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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE DISPOSAL OF

STRAWBOARD AND OIL-WELL WASTES

BY

ROBERT LEMUEL SACKETT

AND

ISAIAH BOWMAN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C., *January 27, 1904.*

SIR: I have the honor to transmit herewith two manuscripts, the first entitled "Strawboard Waste: Its Damage to Water Resources and its Economic Disposal," by R. L. Sackett; the second, "Disposal of Oil-Well Wastes at Marion, Ind.," by Isaiah Bowman, and to request that they be published together as one of the series of Water-Supply and Irrigation Papers.

These papers include a part of the results of investigations made by the division of hydro-economics. The determination of the quality of available waters in the United States and their applicability to domestic and industrial uses involves a consideration of the principal sources of their pollution.

The subjects dealt with in these papers represent two particularly troublesome sources of damage to water resources. The areas in which such damage occurs are very large and important, pollution of the kind considered in the first paper covering the States of Ohio, Indiana, and Illinois, and that discussed in the second paper having been felt in all those parts of the country in which oil wells have been developed.

These investigations were undertaken in an experimental way, and it is hoped that they may serve to direct wider attention to the problems involved, to the end that practical solutions may be reached which will be satisfactory to all those whose interests are involved.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

STRAWBOARD WASTE: ITS DAMAGE TO WATER RESOURCES AND ITS ECONOMIC DISPOSAL.

By Robert Lemuel Sackett.

INTRODUCTION.

Rivers and streams have a commercial value by which they have been universally rated, yet in many cases this rating must properly take into account more than strictly commercial or industrial uses. Water power or shipping facilities have often determined the location of a mill where a city was unforeseen, and the value of the stream as a source of water supply for culinary or drinking purposes has thus often been left entirely out of consideration. But watercourses contribute not only to the commercial value of a location, but to health, and their influence on health has now become an important factor in determining the money value of the lands bordered by them. Health and wealth are in some localities dependent on the condition and flow of streams.

All sanitary authorities now recognize the vital necessity of providing a pure source of municipal or private water supply. Family wells and springs can safely serve but a small proportion of the population. The urban population is now about 50 per cent of the total, and as it grows the percentage dependent on municipal supply will increase. It is to this class of water supplies that this discussion is confined.

SOURCES AND EFFECTS OF STREAM POLLUTION.

SEWAGE POLLUTION.

As the wilderness was subdued by the pioneer, small mills and towns were established on lakes, rivers, and streams. By cutting the forests and draining the cultivated and settled areas the character of the stream flow was changed. Forests are natural reservoirs, where the rainfall is stored, to be given up gradually. Cultivation and drainage aid in producing a rush of water to the streams after rains, which is followed by a period of very low flow in a dry season. The villages in time become cities, drawing their water supply from, and discharging their sewage into, the near-by stream. This source of pollution, in connection with the occasional very low stream flow and consequent slight dilution, has been the cause of great commercial loss, of widespread disease, and of death.

POLLUTION BY TRADE WASTE.

But city sewage is not the only source of stream pollution, for many industries discharge large quantities of refuse, called "trade waste," the presence of which in sewers and streams is very objectionable from a sanitary point of view.

On the continent of Europe and in Great Britain this subject has received considerable attention. The English rivers pollution act of 1876 treats the matter at considerable length, and gives city authorities power to require the adoption of remedial measures by offending factories. In the United States the necessity for legislation restricting pollution by trade waste has only recently arisen. Among the States that have already acted upon this question Massachusetts stands first.

The waste from industries is divisible into three classes—animal, vegetable, and mineral refuse, though many factories discharge two and even all three kinds.

In the first class of waste is included that from abattoirs, packing houses, tanneries, and woolen mills, which discharge large quantities of animal tissue and oil. The decomposition of this matter may be slow, and if deposited on flats it causes unpleasant odors and attracts vermin. If afloat in such quantities that the dilution is not sufficient, the water is dangerous for house use, and even cattle refuse to drink it.

To the second class belong the quantities of vegetable matter which escape from distilleries and from paper, wood-pulp, and strawboard mills—matter for which no present economical use has been found.

To the third class belong the wastes from oil refineries and gas works, which run off mineral oils and heavy tars. When discharged into city sewers these have proved very objectionable, and when discharged into sluggish streams they lodge on shoals and flats with the rise and fall of the water level, coating and killing vegetation, causing unpleasant odors, and fouling the water for dairying and other purposes. Tin-plate and rod mills and galvanizing and plating works discharge large quantities of chemical waste, such as dilute sulphuric or hydrochloric acid, copper sulphate, and sulphate and chloride of iron.

Among other local industries that produce serious nuisance in their vicinity are soap factories, factories using the Solvay ammonia soda process, and white lead, paint, varnish, and starch factories. Certain mineral waters used for curative and bathing purposes and the drainage from mines may also be offensive, but these are not usually amenable to pollution laws. In England they are specifically excluded in the rivers pollution act of 1876. In Pennsylvania the higher courts have passed upon a case involving mine drainage, and the operators were allowed to continue the natural drainage of the mine.

The effect of wastes upon the condition of the stream depends on the relative volumes of stream and of waste, the strength and character of the polluting material, and the proximity of other industries or of

cities requiring pure water and of agricultural lands and residents who might declare a nuisance. It is clear, then, that no general rules can be laid down, but that each case of pollution must be decided on its own merits.

The addition of quantities of organic matter to a stream is highly objectionable, as it furnishes food for the rapid multiplication of disease bacteria which may be present, and it may cause a nuisance by slow decomposition by deposit upon shoals, tidal shores, and flats. Besides rendering the water impotable, abnormal amounts of organic matter cause serious damage to many purifying industries, to sugar factories, meat-packing houses, and canneries. The discharge of mineral waste, unless very highly diluted, hinders the natural purification of the stream, and adds substances that oxidize slowly. This waste kills fish and makes the water distasteful, foul smelling, and dangerous even, to cattle, thus interfering with important agricultural interests and increasing the menace to human life.

MANUFACTURE OF STRAWBOARD.

This report is confined to a careful study of the process of manufacture of strawboard (or pasteboard, as it is commonly called), to the character of the refuse, the nature of the pollution, the damage produced, and the possible means of preventing the pollution.

The principal factories of strawboard in the United States are confined to a comparatively small area. In the report of the United States census for 1900 59 factories are recorded as making strawboard. From 157,534 tons of raw material they produced a finished product valued at $3,187,342. Indiana led with 70,081 tons of board, worth $1,350,636. Ohio ranks second, with 40,531 tons, worth $800,038, and Illinois is third, with 20,100 tons, valued at $382,454. New York, Maryland, and Michigan rank next in order. The first three mentioned make 83 per cent of the board produced in the United States, and Indiana alone produces nearly 50 per cent of the total. The straw used in Indiana cost about $3.90 per ton, and the finished product was worth about $19 per ton.

The strawboard industry does not, of course, include the manufacture of wood pulp, sulphite fiber, or jute.

COMPOSITION OF STRAW.

Strawboard is manufactured from rye, wheat, and oat straw. In England a special straw, known as esparto grass, is used in making paper. Rye and wheat straws are preferred, as they yield the largest per cent of cellulose—the basis of all vegetable fiber. The chemical formula for cellulose is $n(C_6H_{10}O_5)$. The composition of various straws as given by Müller,[a] a German authority, is as follows:

[a] Jour. Soc. Chemical Industry, February 28, 1894, p. 101.

TABLE 1.—*Composition of straws.*

	Winter rye.	Winter wheat.	Summer barley.	Winter barley.	Oats.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Water	14.3	14.3	14.3	14.3	14.3
Organic constituents	82.5	80.2	79.7	80.2	80.7
Ash	3.2	5.5	.....	5.5	5.0
Cellulose	54.0	48.0	43.0	48.4	40.0

James Beveredge, of Northfleet Paper Mills, Kent, England, gives[a] the following results of analyses of straws:

TABLE 2.—*Composition of straws.*

	Zealand wheat.	Dutch wheat.	Dutch oats.	Dutch rye.	Dutch barley.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Water	8.2	12.5	11.2	7.8	11.0
Organic constituents	44.2	43.6	46.0	49.3	47.7
Ash	10.0	7.5	5.5	1.8	7.2
Cellulose	37.6	36.4	37.3	41.3	34.1

In table 1 the organic constituents include cellulose; in table 2 they do not. In the latter the cellulose is unbleached.

Remsen gives the following percentages of cellulose, the straws being in the air-dry state. Rye straw, 54; wheat straw, 48; oat straw, 40. The differences appearing in the above tables are due to differences in the definition of cellulose, in the dryness of the materials, and in the various methods of separation employed. The order of the commercial rating of straws, as given by the strawboard companies, is as follows: (1) rye, (2) winter wheat, (3) spring wheat, and (4) oat. There is generally reckoned a loss of about 40 per cent by weight from the dry straw to the finished board, the latter containing from 5 to 8 per cent of moisture. Various factors enter into the percentage of loss. Straw purchased at harvest time contains a larger percentage of moisture than it contains some months later. The loss of weight from harvest to Christmas time amounts to almost 25 per cent, says an authority in the Journal of the Society of Chemical Industry.[b] Straw grown on light, sandy soils has a much lower specific gravity than that grown on heavy clay or mixed soils. Differences are also caused by weather conditions at harvest time. A wet straw causes greater loss

[a] Jour. Soc. Chemical Industry, February 28, 1894, p. 101.
[b] For February 28, 1901, p. 148.

A. STRAWBOARD ROTARIES.

B. ROTARIES AND STOCK PILES.

and makes a poorer quality of board. The driest material comes from that in the lofts of barns, while straw from stacks is usually damp. It is stated that baled straw is more moist than loose straw.

Of the 48 per cent of cellulose in wheat straw, about 30 per cent is saved by present means of manufacture of strawboard. The machinery and methods employed have not changed materially for many years, and there seems to be little prospect of greater economy being practiced. The reasons for this are discussed later in this paper.

STEAMING IN ROTARIES.

The process employed in the United States is as follows:

The straw is first subjected to a cooking process by steam and lime. A large ellipsoidal rotating steel boiler called a "rotary," shown in Pl. I, *A*, is filled with straw, which is then cooked down with steam, then again filled and cooked down until the rotary boiler has been completely filled. The process of filling a rotary occupies from six to twelve hours. The final charge consists of about 6 tons of straw and 30 bushels, or 2,100 pounds, of lime in the form of milk. This mixture is then rotated and cooked under 40 pounds of steam pressure for twelve hours. Pl. I, *A*, shows the steam line extending through one of the trunnions and the worm gear which rotates the cylinder. This apparently severe chemical and mechanical action results in a rapid softening of the woody fiber and in the reduction of the straw to a dark-yellow, pulpy mass. This "stock," as it is called, is stacked in piles 10 to 15 feet high to drain. Concerning the action which takes place in the rotaries, the Journal of the Society of Chemical Industry says:[a]

> The chemical action of the milk of lime on the encrusting materials surrounding the straw fiber is not a vigorous one. These encrusting materials are not completely, nor indeed to a great extent, separated from the cellulose. The mineral matter remains in the product practically untouched, and if any less quantity than that corresponding to the percentage in the original straw operated upon exists in the prepared pulp, it is due rather to the washing after digestion than to any solvent action of the milk of lime. Milk of lime under certain conditions has a bleaching action upon the straw. It neutralizes the organic acids usually found when fibrous plants are heated for any length of time in the presence of water.

The yield of pulp at this point will be from 75 to 80 per cent of the weight of the original material.

Pl. I, *B*, shows the rotaries, charged from the floor above, and the elevators that carry the stock from the rotaries and dump it in the piles shown in the foreground. At the extreme left is an endless-chain elevator which carries the stock to the beater room.

The material is allowed to stand in these piles for twenty-four hours or more to drain. After it is thus drained it contains about 50 per cent of water and from 6 to 7 per cent of lime. This is equivalent to from 12 to 14 per cent of lime in the dry straw. Since the original charge

[a] For February 28, 1894, p. 101.

of lime and straw was in the proportion of 2,100 pounds of lime to 14,100 pounds of straw and lime, or about 14 per cent lime, practically none of the latter has drained out with the condensed steam. This drainage from the stock piles forms but a small part of the waste sewage. It is straw colored and very turbid, carrying a small quantity of fiber broken fine in the rotaries.

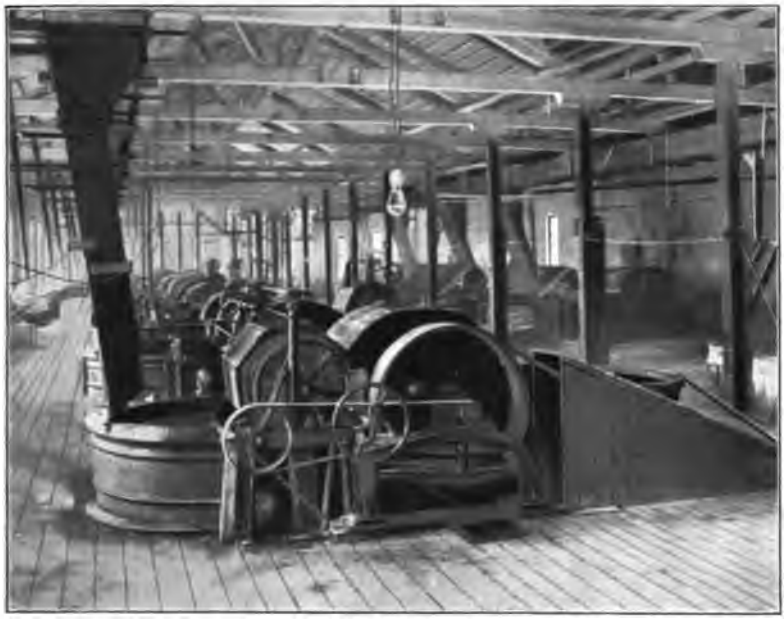
WASHING.

This process is much more drastic, and it is here that the great volume of waste is produced.

The stock is run through washing machines for the purpose of removing the lime. A row of washers in operation is shown in Pl. II, *A*. At the left is the chute from the conveyor above, down which the stock is fed. To the right of the chute are the water pipes. The washing machine consists of an oval channel about 3 feet wide, around which the stock travels, being supplied with copious volumes of water. Across this channel is placed a cylinder, 42 inches in diameter and 42 inches long, having longitudinal ribs or flanges about three-fourths of an inch square in section and three-fourths of an inch apart. Meshing with this, like the teeth of geared wheels, is an idler, below, of similar size and form. These wheels, revolving, lift the water and straw to a level several inches higher than that in the oval channel, whence it flows by gravity halfway around its course to a point where it meets a revolving brass screen of fine mesh, through which a part of the water escapes, carrying with it the finer particles of fiber and free lime. The remaining straw, with additional volumes of fresh water, now passes many times through the rolls, which further mash and break the fiber, and around to the screen, where more straw, lime, and water escape. The total waste is enormous. It now takes about 40,000 gallons of water to wash 1 ton of straw. About 3,200 pounds of straw and 560 pounds of lime are required to make 2,000 pounds of board. A small amount of lime remains in the board; hence 1,200 pounds of straw and about 500 pounds of lime are washed out by the 40,000 gallons of water. An idea of the volume of waste may be conveyed by giving the capacity of an average mill. Such a plant uses 50 tons of straw and nearly 10 tons of lime during every twenty-four hours. From 1,000,000 to 2,000,000 gallons of water are employed in the rotaries, washers, and vats. This volume of water carries away with it about 19 tons of the straw and practically all of the 10 tons of lime each twenty-four hours.

DRYING.

After the washing process the straw, with a considerable volume of water, is led to a train of rolls, consisting of three parts—first, the wet end; second, the hot rolls; third, the trimming and cutting machine. As it comes from the washers the material is run into vats,



A. PULP WASHERS.

B. SETTLING BASINS.

where it is mixed with large quantities of water and passed over hollow cylinders having fine wire-cloth faces, which allow the water to escape, leaving the fiber on the surface of the cylinder. The fiber is then taken by woolen felts, which are pressed down on the surface of the cylinder. This makes a web of paper on the felt. The pulp, which is now about one-third straw and two-thirds water, travels up and down, over and under a double train of hot rolls, heated by steam that is carried in through hollow bearings. As the pulp passes on through the train it is constantly pressed and dried, until finally it is separated from its cloth support and goes to the trimming machine, where it is cut into sheets of proper size. It now contains about 10 per cent of water and a small quantity of lime. The board is manufactured in many thicknesses and weights. Just before it is trimmed it may be coated on one or both sides with a thin paper facing or finish.

METHODS OF DISPOSAL OF WASTE.

The waste liquors from the rotaries and washers, and that from the vats where it is not used over again in the washers, are run together and discharged into a trough or ditch, leading in some cases to a neighboring stream. The effect of these wastes upon the stream depends upon its character and volume. As many Indiana rivers flow over limestone beds, their water is hard, carrying 15 to 20 grains of lime per gallon. But the waste liquor from a strawboard mill contained in one case a minimum of 66 grains per gallon (an amount which has recently been doubled by a decrease in the quantity of water used), and in some cases, where wash water is not plentiful, the quantity of lime reaches 200 or more grains per gallon. In order to reduce the quantity of lime to 40 grains per gallon the minimum stream flow would need to be about ten times the volume of water employed in the process. This would require a stream that discharged, in time of drought, from 10 to 20 million gallons in twenty-four hours. This limits the number of streams upon which such mills can be operated in the present manner without nuisance, to a few rivers in each State.

On account of the clearing of forests, artificial drainage, and irregularities of rainfall the flow of Indiana tributaries becomes extremely low in the late summer and fall. Some, indeed, cease to be more than isolated ponds, the water seeping through the gravel beds. Under these circumstances, if not under normal conditions, the discharge of sludge into a stream produces results that demand very serious consideration. The straw waste, when deposited on flats from which the water has receded, decomposes very slowly, its decay being in part retarded by the presence of lime and silica. Remsen says that as much as 73 per cent of the ash of wheat straw is silica. As the analyses given in table 4 (p. 27) show, the quantity of ammonia present

in the waste is very large, and this is undoubtedly the principal cause of the very slow decomposition.

At some places the solid part of the waste has been heaped on large tracts of land. In these cases the stench produced has been carried by the wind for a considerable distance, causing a nuisance.

Mr. Sweeney, commissioner for fisheries and game for Indiana, in his biennial report for 1901 and 1902, speaking of the conditions which tend to destroy fish, says, on page 11:

> Greater than all other artificial means is the pollution of our streams with the refuse from strawboard mills, oil wells, and pulp mills. This refuse covers the spawning beds and prevents the eggs from hatching, while it penetrates the gills of the living fish and kills or drives them from the streams.

The quantity of lime would in some cases be such as to kill the fish if the straw did not. Game fish are not to be found in polluted waters. Thus the interests of the State enter into the question of stream pollution by strawboard mills.

In other cases the method of disposal has been modified by running the waste into a series of beds scooped out of a gravel bottom land. Here the straw and lime slowly settle, the water filtering through the subsoil and finding its way to the neighboring creek. But the great quantity of straw waste soon clogs such natural filters as have been tried. High water is depended on to wash the refuse out of the beds, whence it is deposited on other lands below; so that the method is only a makeshift.

What a carefully constructed settling and filtering plant may accomplish has not yet been determined. During the summer of 1903 the American Strawboard Company built at one of its factories a series of basins, shown in Pl. II, *B*, Pl. III, and fig. 1. Basins Nos. 1 to 5, fig. 1, average an acre each, while No. 6 is about 2 acres in area. Levees from 4 to 6 feet high were built, so that the basins could be filled to a depth of about 5 feet. From the old ditch which is shown in fig. 1 a spout was constructed to conduct the waste into basin No. 1. From this basin it flows diagonally to a weir at the opposite corner, where it enters basin No. 2. The flow is diagonally across each basin to the next in order through the series, to No. 5 or No. 6. From basin No. 5 a gate leads to filter No. 1, and from basin No. 6 a similar gate leads to filter No. 2. These filters have lines of 8-inch tile laid 25 feet apart and covered with 2 feet of gravel. The underdrains lead to the open ditch between the two filters. Each basin has a gate leading to the river, so that the waste can be run through any number of settling basins and then into the river or through the filters. The waste was turned into basin No. 1 in the early summer. When it had filled, the overflow ran into basin No. 2, and so on, basin No. 6 being filled in late summer.

SETTLING BASINS AND FILTER BEDS.

It seems inevitable that in time there will be a large deposit of straw and lime, which will have to be scraped off the basins and filters and carted away. Seepage through the walls and bottoms of the basins will decrease and the filters will clog until the efficiency has reached an unsatisfactory point. The period of time which will elapse before

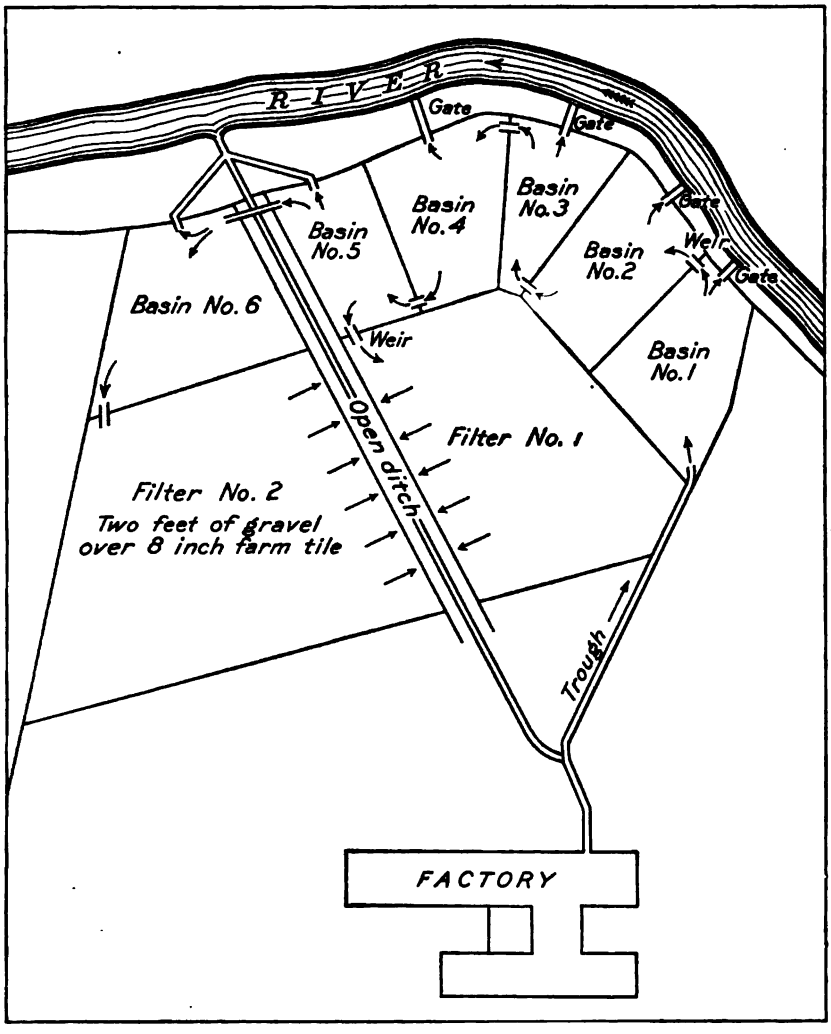


FIG. 1.—Plan of strawboard settling basin.

this condition arises and the effectiveness of months of sedimentation, with or without filtration, will not be known until a season has passed.

At one of its plants the American Strawboard Company used a trough-shaped device for separating the fine straw from the waste water. A vat 16 feet long was constructed, the end view of which

was practically an equilateral triangle. The waste as it came from one of the washers was discharged into this vat, so that the water started downward, then turned upward through a screen, leaving the straw to continue downward. The screens clogged in the course of time and had to be cleaned by hand. The vat held about 7,000 gallons and treated 70,000 gallons in twenty-four hours.

As the waste passed from the washers to the vat the analysis was as indicated in the first column, and the analysis as the water came from the vat is recorded in the second column.

Analyses of strawboard waste before and after passing from washers to vat.

[In parts per 100,000.]

	Before.	After.
Suspended matter:		
Organic matter	565.7	188.6
Inorganic matter	393.1	123.3
Total residue	958.8	312.5
Total solids:		
Organic matter	1,294.5	528.5
Inorganic matter	661.8	244.3
Total residue	1,956.3	772.8
Calcium	510.5	204.8

It will be seen that the vat removes about 66 per cent of the suspended matter. The latter is, however, abnormally high, and the effluent still contains 312.5 parts per 100,000—five to ten times what it should before passing to a stream. Increasing the size of vat and decreasing the rate of flow, with some changes of design in order to emphasize the upward-flow principle, might lead to a design which would be sufficient where the stream flow and dilution were high.

No bacterial treatment such as is employed in the purification of sewage will avail in this case, as the treatment with lime and steam in the rotaries destroys all the bacteria present. A considerable period must elapse for the cultivation of such organisms.

EXPERIMENTS ON DISPOSAL OF WASTE.

To determine the possibility of other and more efficient methods of disposal than those just outlined, the author was appointed to take charge of a series of experiments on strawboard waste and to report their results to the United States Geological Survey. His instructions were to study the process of manufacture, analyze the waste liquor, and find the efficiency and cost of various methods of disposal, in order

that some recommendation might be made to the authorities or to the manufacturers when circumstances should demand a change in the method of disposal.

The expense is a very important item, as it is easy to find a method of treatment by which the waste can be purified, but the cost would prevent the operation of the mill. Other methods will clarify the waste, but leave the water extremely hard, thus accomplishing but half the purpose. Theoretically, the liquid which eventually flows into the stream ought not to be harder than the normal stream—a condition extremely difficult to fulfill by commercial methods. Likewise, the total solids should not be above an average amount contained in natural waters.

METHODS OF PURIFICATION.

There are three general methods of treatment for the purification of polluted water—sedimentation, filtration, and chemical precipitation.

SEDIMENTATION.

This process consists of letting the liquid stand for a period of time long enough to allow the matter held in suspension to settle to the bottom. There is no chemical action involved, but since organic as well as inorganic matter may be settled, future chemical changes are possible. The hardness or acidity will not be changed. The rapidity and efficiency of the process depend on the specific gravity of the suspended matter. Silt will settle quickly, and this process is frequently used to remove such objectionable material from water supplies.

In the case of strawboard wastes, the particles of straw are so fine and the specific gravity is so slightly above unity that the downward motion is very slow. A jar 10 inches high will settle about 10 per cent of its solid matter in twenty-four hours. In twenty-four hours more the change is very slight. At the end of twenty-four hours, color, turbidity, odor, and taste are about the same as before such treatment. The storage capacity required for twenty-four hours' settling would be twice the capacity of the mill. To settle forty-eight hours reservoirs that would contain three times the volume of refuse would be required, and so on. From 2,000,000 to 4,000,000 gallons' storage would be needed for such treatment.

Even with still longer periods of sedimentation the hardness would remain practically unchanged, as the only lime precipitated would be due to the CO_2 absorbed from the atmosphere.

FILTRATION.

The process next to be described, and one now very frequently used in the purification of water supplies and of sewage, is filtration. The water is allowed to pass slowly through a bed of charcoal, coke, furnace

slag, or sand. The process is partly a screening one, but under proper conditions a very efficient bacterial action takes place, in which the healthful bacteria assist in reducing the organic matter to its constituent elements. *Bacillus coli-communis*—the biological index of sewage pollution—disappears, and not only suspended matter but the amount of chlorine is reduced, and the number of bacteria per cubic centimeter is decreased by from 95 to 99 per cent of the number present in untreated water.

There are two kinds of filters, mechanical and slow sand filters. In the former the rate of flow is higher and frequent cleansing is necessary, while in the sand bed the rate of filtration is much less and the filter purifies itself in part while resting or while in action. If the surface becomes clogged, occasional rakings are necessary in order to remove the clogged surface and restore it to its normal state.

CHEMICAL PRECIPITATION.

In this process the liquid is treated with a previously determined quantity of some chemical which will cause a reaction involving the production of a solid in the form of grains or flakes. As the precipitant has a specific gravity greater than water, it falls and drags down with it other solids. The rapidity of its action depends on the proper proportioning and mixing of the agents employed and on the weight of the particles and their size. A flocculent, heavy precipitate rapidly carries down with it a large proportion of the organic and inorganic matter that has been held in suspension.

Such processes are usually continuous; the fluid to be treated and the reagent are automatically mixed and fed in at the bottom of the tank, the current being upward. The purified liquid is taken from the top of the tank and the precipitated sludge is drawn from the bottom. Certain limitations have been found in the successful operation of the upward-flow principle. Hans Benedikt, in Die Abwasser der Fabriker (Trade Waste), states that the normal downward velocity of suspended matter in still water must be at least 2 millimeters per minute. He also says:

> If it be desired to perfectly clarify by deposition, on the upward continuous flow principle, water which is naturally charged with suspended matter, or by the addition of precipitants, a transverse section of more than $0.002 \times 60 = 8.33$ square meters is required to obtain 1 cubic meter per hour of clear water, in order that the upward velocity of the water may be less than the downward velocity of the particles.

The chemicals most frequently employed in water purification are alum, sulphate of iron, lime, copperas, and combinations of these. It is very important that the proportion of coagulant be always correct, else either the action is not completed or unnecessary waste results from overcharging.

COAGULANTS USED.

The series of investigations was begun by using small quantities of waste liquor—from 50 to 100 cubic centimeters—and trying the effects of various chemicals in different quantities.

ALUM.

The effect of alum was rapid, showing that it is a very satisfactory coagulant. The liquid was left slightly turbid and with some odor. The hardness was not affected. The chemical action was as follows:

$$3CaO_2H_2+Al_2(SO_4)_3+K_2SO_4+24H_2O=3CaSO_4+Al_2O_6H_6+K_2SO_4+24H_2O.$$

The quantity of alum is to the quantity of calcium oxide as 948 is to 168. About 112,000 pounds of alum is needed daily to treat waste water containing 19,800 pounds of lime and straw.

The usual process for producing alum, or sulphate of alumina, is to treat the mineral bauxite with sulphuric acid. In England some mills have found it very cheap to make the necessary quantity in their own plant. The resulting cake, according to Naylor in Trade Waste, page 21, is 36 per cent sulphate. The cost is $4.70 per short ton of product or $13.40 per ton of pure sulphate.

In the United States, on account of the excessive cost of bauxite and sulphuric acid, commercial sulphate 57 per cent pure will cost about $16 per ton delivered, or $28 per ton of pure sulphate delivered. The daily expense for 56 tons would be $1,568. This cost of partial purification, omitting other items, would absolutely prevent the operation of any mill consuming 50 tons of straw a day.

Not only is the expense objectionable, but the quantity of lime in the water, making the water permanently hard, must be reduced, else the process is not satisfactory.

SULPHATE OF IRON.

Ferrous sulphate is used in water-purifying processes, giving a dark-brown precipitate. The action is rapid and the clarification satisfactory. The use of one atom of iron for each molecule of calcium oxide present in the water produces the following reaction:

$$CaO_2H_2+FeSO_4=CaSO_4+FeO_2H_2.$$

When the proper amount of ferrous sulphate is added to 100 cubic centimeters of strawboard liquor the precipitation is almost instantaneous, and in five minutes the solid portion lies at the bottom in a brownish cake. The liquid above is very clear, having only a slight greenish tinge.

Since a daily output of 19,800 pounds of lime is assumed as a working basis, in order to make the comparison of cost apply to a particular mill 19,800 pounds of iron would be needed and 34,700 pounds of sulphuric acid.

The proper process would be to treat scrap iron with sulphuric acid in a reservoir. The expense would be—

19,800 pounds iron, at $7.50 per ton of 2,000 pounds	$75
34,700 pounds sulphuric acid (H_2SO_4), at $12 per ton	208
Cost of treatment	283

The same objections apply to the use of sulphate of iron as to alum. The expense is too great, and lime remains in the form of $CaSO_4$, which leaves the permanent hardness very high.

Instead of using sulphate of iron as above produced, the crude sulphate, copperas, a by-product of certain processes, can be employed. It is 25.9 per cent ferrous oxide and 28.7 per cent sulphur trioxide (SO_3). Roughly, 4 tons of copperas, at $9 per ton delivered, would treat 1 ton of lime. For 19,800 pounds of lime nearly 40 tons of copperas would be required, at a cost of $360 daily. While this process would be more economical than the use of sulphate of iron, when all items of expense are figured, still the cost is excessive and the process impossible as a general treatment for all the waste from a strawboard mill.

LIME.

Lime is one of the most common coagulants used in clarifying drinking waters. The usual stream carries a small amount of carbon dioxide, which combines with from 5 to 10 grains of calcium oxide to form calcium carbonate, which precipitates in fine, white particles, dragging down such organic and inorganic solids as may be held in suspension.

This process fails in treating strawboard refuse because the liquor is already many times overcharged with lime, by a part of which the little CO_2 that was in the water has been greedily used and the remaining lime is seeking more. The addition of milk of lime does not produce perceptible action.

CARBON DIOXIDE.

The facts above mentioned led at once to the conclusion that carbon dioxide must be fed to the waste liquor. On applying the computed amount of CO_2, it was found that but little precipitation actually occurred. The reason for this may be stated as follows: (1) $CaO+H_2O=CaO_2H_2$, or the lime in the waste liquor is in the form of calcium hydroxide. (2) On applying CO_2, $CaO_2H_2+CO_2=CaCO_3+H_2O$, precipitation by CO_2, occurs; but at the same time the lime is redissolved, as follows: (3) $CaCO_3+H_2O+CO_2=H_2Ca(CO_3)_2$, making a bicarbonate of lime. No precipitation has yet occurred. But if to the double carbonate of lime we add milk of lime the following action takes place: (4) $H_2Ca(CO_3)_2+CaO_2H_2=2CaCO_3+2H_2O$. Reprecipitation now takes place, carrying down the straw and calcium. The flakes are very large and the downward velocity is exceptionally rapid. In five minutes the

liquor has cleared at the top and in twenty minutes the process is completed.

CARBON DIOXIDE AND MILK OF LIME.

As above indicated, it is not sufficient to apply limewater or carbon dioxide alone, but upon first saturating the liquor with CO_2 and then supplying the proper amount of milk of lime the result is very satisfactory. It will be observed that not only is the straw removed, but the water comes out soft; that is, the calcium also is removed. None of the previous treatments will precipitate the lime.

It is observed that the amount of CO_2 required for the previous reactions is two molecules per atom of calcium in the waste liquor.

From (4) it appears that the amount of calcium added as milk of lime equals the amount present in the waste liquor. Assuming that the finished strawboard does not contain more lime than is in the river water used, there are needed 19,800 pounds of lime as precipitant.

The following analyses, made by E. J. Macy under the direction of Prof. W. D. Collins, at Earlham College, will present the important facts in concrete form:

TABLE 3.—*Residue contained in strawboard waste liquor.*

[In grams per 100,000 cubic centimeters.]

	Raw liquor.	After precipitation with CO_2 and milk of lime.	
		Filtered after settling 1 hour.	Filtered after settling 24 hours.
	Grams.	*Grams.*	*Grams.*
Total residue	293.66	137.59	33.325
Combustible residue	134.63	65.63	31.250
Absolute residue	159.03	71.50	1.800

The absolute residue is a white powder, principally calcium oxide.

The above results were obtained by treating 350 cubic centimeters in a tube seven-tenths of a meter high. This form was chosen in order to approximate the depth of tank which might be employed on a larger scale. The proportions of height to cross section were not those which would be used commercially, and hence the fall of particles was hindered much more by friction against the sides of the vessel than they would have been in a larger container. After settling one hour, 53 per cent of the total solids are removed and 55 per cent of the absolute residue, principally lime. After settling twenty-four hours, 89 per cent of the total solids are removed and 98.8 per cent of the absolute residue.

EXPERIMENT STATION.

A light structure, 8 by 12 feet in plan and 14 feet high, with three stories or platforms, was erected on the grounds of Earlham College, Richmond, Ind., for the treatment of strawboard waste in larger quantities. The filters were on the lower platform and were provided with sewer connection. Above the platform was the barrel in which the precipitants were added to a given quantity of liquor. On the upper platform was the limewater and a tank for generating gas under sufficient pressure to force it against a head of 3 feet of water.

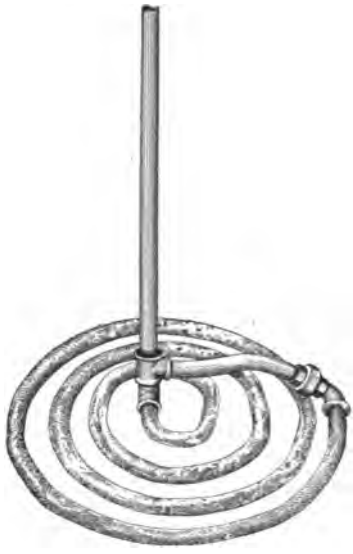


FIG. 2.—Carbon-dioxide distributor.

The gas tank consisted of a steel cylinder with a screw top closing on a gasket. A valve connection was made at the upper end and a standpipe by which to add acid. The tank was charged with a quantity of limestone. Then the proper amount of hydrochloric acid was turned down on the limestone from a reservoir within the tank. The quantity of acid was made sufficient to generate and to deliver to the waste the required amount of CO_2. A charge of 35 gallons of waste as fresh as could be obtained was saturated with CO_2, the gas being distributed through the waste by means of holes in a coil of half-inch gas pipe placed near the bottom of the tank. (See fig. 2.) The coil could be raised or lowered, and, as was expected, the best results were obtained with the gas distributor as low as possible.

The limewater was discharged through perforated pipes, shown in fig. 3, radiating from a central vertical main. The holes were arranged in such manner as to cause a swirl of the waste, which produced a very thorough mixture.

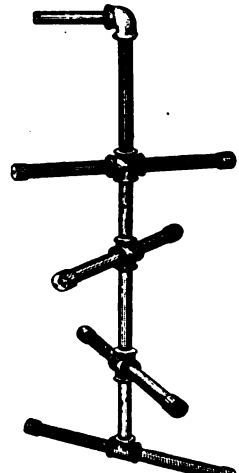


FIG. 3.—Milk-of-lime distributor.

The order of procedure was, first, to measure a certain amount of waste in the calibrated precipitation tank; second, to charge the gas generator, which delivered the proper amount of CO_2 in about ten minutes, and to apply the limewater—about 5 gallons. The resulting action was immediate. A heavy cloud of large particles formed and began a descent which indicated a specific gravity much larger than unity. The surface began to clear at once, and after settling from five to thirty minutes the process of siphoning the clarified liquor onto the filter below was begun.

The filters consisted of barrels filled with varying quantities of coarse gravel, fine gravel, and sand. These were operated at different rates, and the efficiencies were determined from analyses. Samples of the effluent and of the filtrate were taken from each barrel, and the results are recorded in table 4 (p. 27). These samples were taken when about one-half of the barrel had been treated. Five gallons of sludge were left in the bottom of the precipitation tank. This was a thick, sirup-like mass of dark-yellow straw, slightly whitened by the excess of lime that was sometimes present when a surplus of milk of lime was used.

Two molecules of carbon dioxide are required for each molecule of lime present. The strawboard company reported that 2,000,000 gallons of water were used to carry away the 19,800 pounds of lime wasted. This is equivalent to 66 grains per gallon, or about 100 parts per 100,000. The quantity of CO_2 needed was, presumably, 200 parts per 100,000 of waste.

An amount of lime should be added equal to that present in the waste, or the total lime thrown down should be about 200 parts per 100,000. As shown in table 3 (p. 23), the absolute residue in one sample of untreated strawboard waste, taken at random, was 159.13 parts per 100,000, showing an increase of 50 per cent in the proportion of lime. There is some variation in the quantity of lime used, depending on the quality of the straw, and a still greater range in the volume of water wasted.

A standard treatment was decided upon, in which the proportions were 200 parts of CO_2 and 5 gallons of limewater (or about 150 parts of lime) to 100,000 parts of waste. The color of the solid matter thrown down showed that the precipitants were sometimes used in excess.

DESCRIPTION OF EXPERIMENTS.

SINGLE BARREL TESTS.

Tests were first made by single barrels, in the manner and with the results shown below:

Barrel No. 1.

Thirty gallons of waste.

Carbon dioxide equal to 200 parts per 100,000.

Five gallons of limewater.

Stirred and allowed to settle thirty-five minutes.

Siphoned 30 gallons off in thirty minutes onto filter composed as follows: A barrel with 9 inches of very coarse gravel in the bottom; then 5 inches of gravel from one-fourth to 1 inch in diameter; next, 10 inches of coarse sand, and finally, on top, 7 inches of fine washed sand.

The area of the surface of the filter was 4.50 square feet, or about one nine thousand six hundred and eightieth part of an acre.

The rate of filtration was about 13,000,000 gallons per acre daily, which was, of course, too fast to accomplish much. Both filtrate and effluent were colored, strong in taste, and smelled of lime. No samples were taken.

Barrel No. 2.

Thirty-five gallons of strawboard waste.
Carbon dioxide.
Five gallons of limewater (milky).
Settled twenty minutes.
Siphoned 30 gallons onto filter in 1 hour and 52 minutes.

The precipitated matter, 4 inches deep, was light yellow. Free lime present. Sample after precipitation 50 per cent cleaner.

The effluent was still clearer, with bitter taste and some odor, and was still yellow color.

Filtration was at the rate of about 3,500,000 gallons per acre daily, which removed about 16 per cent of the lime that came to it (see sample 2, table 4).

Barrel No. 3.

Thirty-five gallons of strawboard waste.
Carbon dioxide.
Five gallons of limewater.
Fourteen minutes to charge with gas.
Settled six minutes.
Time of filtration, two hours and twenty minutes.
Rate of filtration, 2,780,000 gallons a day.

Filter, 9 inches of coarse gravel in bottom, 2 inches of fine gravel, 16½ inches of fine washed sand on top.

The liquor from precipitation tank showed 244.18 parts per 100,000 of lime. After filtration it showed 177.68 parts. Efficiency of filter equals 27.6 per cent. Color and taste noticeable.

Barrel No. 4.

Thirty-five gallons of strawboard waste.
Carbon dioxide.
Five gallons of limewater.
Took seventeen minutes to charge with carbon dioxide.
Settled six minutes.
Time of filtration, three hours and forty-five minutes.
Rate of filtration, 1,730,000 gallons per acre daily.

Filter, 2 inches of very coarse gravel in bottom, 2 inches of gravel, then, on top, 22 inches of medium washed sand, which passed sieve of one-eighth inch mesh.

It will be noticed in sample 4, table 4, that the effluent from the precipitation tank contained only 85.12 parts of lime per 100,000, or about one-third that found in the previous cases and about 53 per cent of the absolute residue in the untreated sample of table 3. It is certain that more than 50 per cent of the absolute residue was removed by the process of precipitation. On the other hand, the filter apparently accomplished nothing. This result is probably due to lime which was carried over in the previous work and which was washed out of the filter with the present filtrate.

TABLE 4.—*Amounts of calcium, free ammonia, and albuminoid ammonia contained in effluent of strawboard treated with carbon dioxide and lime water in experiments at Earlham College, Indiana.*

[In parts per 100,000.]

	Sample No. 2.		Sample No. 3.		Sample No. 4.	
	Before filtration.	After filtration.	Before filtration.	After filtration.	Before filtration.	After filtration.
Calcium	283.024	236.868	.....	.....	85.12	89.78
Free ammonia	1.675	.7	.835	.8	2.50	3.0
Albuminoid ammonia	1.125	1.336	1.0	.7	1.0	1.15

TEN-BARREL TEST.

In order to approach commercial methods as closely as seemed possible in a small experimental plant, a test of 10 barrels of strawboard waste was arranged to close the work.

First. Three barrels of waste were run through the precipitation tank, filling it and two other barrels, which served as reservoirs. The milk of lime and CO_2 were fed continuously and in proportion to the rate at which the waste flowed. It was difficult to regulate the flow of the waste by valves, as the straw would choke them, thus varying the discharge. It was therefore necessary to make the rate of flow into the precipitation tank high. Automatic floats could not be used to properly proportion the waste and lime, as the volume discharged was too small to overcome the friction of such devices.

The two reservoir barrels were allowed to stand twelve hours; then samples were taken from the top of each. The first barrel was siphoned onto a coke filter, consisting of a barrel with 2 feet of fine coke breeze, the top 6 inches of which consisted of particles one-fourth inch in diameter.

The second barrel was siphoned onto a sand filter having 6 inches of fine gravel in the bottom and 24 inches of fine sand on top. The latter passed a sieve of one-eighth inch mesh.

The rate of filtration was 50 gallons in twelve hours. As the filters were approximately 0.0001 of an acre in area, the rate of filtration through the coke was 1,000,000 gallons per acre per twenty-four hours. The rate through the sand was half as rapid, or 500,000 gallons per acre daily.

Precipitation and settling in the first barrel removed 47 per cent, and in the second barrel 90 per cent, of the suspended matter. The coke filter accomplished practically nothing. The sand filter removed 25 per cent of the suspended matter reaching it, making the total removal by precipitation, twelve hours' sedimentation, and sand filtration, 92.6 per cent. The greater efficiency of the precipitation into the second barrel was due to a better adjustment of the proportions of lime and CO_2 to the waste.

Second. Two reservoir barrels were again filled in order by the effluent from the precipitation tank. Each settled one hour. Then one filtered through the coke, the other through the sand, each at the rate of 50 gallons per twelve hours, or 1,000,000 gallons per acre daily. The efficiency of the precipitation and settling one hour was 20 per cent; of precipitation, settling one hour, and sand filtration, 90 per cent.

Third. In another and similar case the efficiency of precipitation and settling thirty minutes was 75 per cent; of precipitation, settling thirty minutes, and sand filtration, at the rate of 50 gallons in six hours, or 2,000,000 gallons per acre daily, 80 per cent.

Fourth. Similarly the efficiency of precipitation and settling fifteen minutes was 80 per cent, while the addition of sand filtration at the rate of 4,000,000 gallons per acre daily removed 86 per cent of the suspended matter.

Fifth. In another case the efficiency of precipitation and settling twelve hours was 92 per cent; of precipitation and settling eighteen hours, 86 per cent.

Sixth. The precipitation tank was run continuously, and two samples taken from the top showed 47 per cent, and fifteen minutes later 60 per cent, of the suspended matter removed. The gas bubbled up throughout the entire cross section of the precipitation tank. This constant ebullition prevented the suspended matter from settling as it should and as it would in a tank described later, in which the ebullition is confined to the delivery pipe, in which the flow is downward to the bottom of the precipitation tank.

Seventh. The waste and milk of lime were delivered at the bottom of the precipitation tank, where the gas was added, at the rate of 100 gallons in twelve hours. The effluent taken from the top was delivered into the bottom of a reservoir barrel. From the top of it ran two siphons—one to the coke and one to the sand filter—each discharging at the rate of 50 gallons per twenty-four hours, or 500,000 gallons

per acre daily. The precipitation removed 36 per cent of the suspended matter, and the coke filter removed 42 per cent of the remainder. At the same time the sand filter removed 66 per cent. The total efficiency with the sand filter was 79 per cent.

Eighth. The sludge drawn from the bottom of the precipitation barrel showed 9,884 parts per 100,000 of suspended matter, or 40 times that in the untreated waste.

DISCUSSION OF TESTS.

The above efficiencies are all figured on the basis of a single sample of untreated waste which contained 238.9 parts per 100,000 of suspended matter. To have taken a sample from each barrel would have increased the number of analyses by ten, and would not have effected the results materially. As it was, 21 analyses were made. Different barrels differ in the quantity of suspended matter, of total solids, and of calcium present. The quantity of lime was sometimes too great, and at other times the quantity of CO_2 may not have been sufficient. These facts account for the discrepancies that arise. The average efficiency of precipitation in removing suspended matter from 10 cases was 63 per cent. The average efficiency of precipitation, settling for various periods, and sand filtration was over 85 per cent.

TABLE 5.—*Analysis of sample of untreated waste from fourth barrel.*

[In parts per 100,000.]

Suspended matter:	
Organic residue	149.8
Inorganic residue	88.8
Total residue	238.6
Total solids:	
Organic residue	362.5
Inorganic residue	181.0
Total residue	543.5
Calcium	160.6
Nitrates	None.
Nitrites	None.
Chlorine	71.8
Ammonia, free	.74
Ammonia, albuminoid	.60
Reaction, alkaline.	
Coloring, organic.	

TABLE 6.—*Residue contained in suspended matter in samples 2 to 21.*

Sample.	Total residue.	Organic residue.	Inorganic residue.
No. 2	125.8	57.2	68.5
No. 3	128.7	86.5	42.1
No. 4	23.5	16.0	7.4
No. 5	17.7	11.0	6.7
No. 6	200.0	133.7	66.2
No. 7	215.0	160.3	54.6
No. 8	62.0	43.9	17.9
No. 9	24.0	14.0	9.5
No. 10	60.5	36.8	23.5
No. 11	48.0	29.3	18.6
No. 12	195.8	123.5	71.9
No. 13	33.8	24.4	9.3
No. 14	152.0	105.3	45.6
No. 15	88.8	61.0	27.6
No. 16	50.0	35.0	14.9
No. 17	126.5	75.3	51.1
No. 18	89.5	51.5	37.9
No. 19	19.0	12.5	6.4
No. 20	33.6	11.1	12.3
No. 21	9,884.0	5,361.6	4,501.5

Samples 2 and 4 were taken from the tops of the reservoir barrels. Samples 3 and 5 are of filtrates from the coke and sand filters, respectively, taken at the middle of each test. The barrel from which sample No. 2 was taken was run through the coke filter. The barrel from which sample No. 3 was taken was filtered through sand.

Reservoirs Nos. 1 and 2 were filled and permitted to settle one hour, after which samples Nos. 6 and 7 were taken from reservoirs 1 and 2, respectively. Reservoir No. 1 was then run through the coke filter and No. 2 through the sand filter at the rate of 1,000,000 gallons per acre a day. Samples 8 and 9 are from the filtrates through the coke and sand, respectively.

Reservoir No. 1 was filled and allowed to settle thirty minutes. Sample No. 10 was then taken from the top. It was siphoned onto the sand filter at the rate of 2,000,000 gallons every twenty-four hours. Sample 11 is from the filtrate.

Reservoir No. 2 was filled and allowed to settle fifteen minutes. Sample 12 was collected as the liquor was siphoned from the top of reservoir No. 2 onto the sand filter, through which it passed at the rate of 4,000,000 gallons per acre daily. Sample 13 is from the filtrate.

The precipitation tank was run continuously, discharging into reservoir No. 1. From the top of the latter siphons led to the coke and sand filter. The rate of discharge from each was 50 gallons in twelve hours, or 1,000,000 gallons per acre daily. Sample 14 was taken from the top of the reservoir. Sample 15 was from the filtrate through the coke, and 16 from the filtrate through the sand.

Sample 17 was taken from the top of the precipitation tank during its operation, and sample 18 was collected fifteen minutes later.

Sample 19 was obtained from the top of the precipitation tank after it had settled for a period of twelve hours.

Sample 20 came from the top of the precipitation barrel after it had settled eighteen hours.

Sample 21 is of sludge drawn from the bottom of the precipitation tank.

The effect on solids in solution, especially on the calcium, was not so satisfactory, owing to the lack of sensitive apparatus by which to gauge the proper proportions of milk of lime. There was either an excess or a deficiency of lime, leaving an undesirable amount in the effluent. So long as the quantity of CO_2 is sufficient to saturate the liquor no variation in it is needed, but for the most successful operation of the process the volume of lime should be automatically regulated by the rate of flow of waste.

MIXING APPARATUS.

English and American experience suggests that the waste, CO_2, and milk of lime should be brought together during a downward flow, and that the precipitation should take place during a following slow, quiet, upward movement.

The milk of lime may be proportioned to the waste by a float in the chamber leading to the waste weir. This float would vary the length of a weir of constant head which feeds the milk of lime to the waste. The mixture should then travel down a central shaft through a nest of tubes perforated on the lower side, from which CO_2 issues under about 2 feet of head. The treated waste now travels down the central shaft to the bottom of the tank, where the flow turns upward with a very low velocity. The less the upward velocity the greater the efficiency of precipitation. The effluent would be collected at the top in semicylindrical troughs.

In the tests above reported 50 gallons were run through a tank of 50 gallons capacity in one hour. The cross section of the barrel was 649 square inches, making an upward velocity of 0.005 of an inch per second. To treat 1,000,000 gallons a day with the same upward velocity would require a tank of 83,300 gallons capacity, or 25 feet square and 15 feet deep. In the tests made the CO_2 was distributed throughout the barrel, and the violent ebullition kept the precipitation from

being satisfactory, unless 15 to 30 minutes be given or the effluent be run into settling reservoirs. By confining the ebullition to a central small cylinder, where the downward flow takes place, the efficiency of the precipitation would certainly be increased.

PRODUCTION OF CARBON DIOXIDE.

The most important problem in the application of this method of purifying strawboard waste is the production of the required amount of carbon dioxide in an economical and practical manner. Two methods of producing this may be considered.

First method.—Carbon dioxide may be produced by burning lime in closed kilns, such as are used in the manufacture of beet sugar. In the typical factory which we have assumed, using 50 tons of straw a day, nearly 10 tons of lime are needed in the process of manufacture, and an additional 10 tons are required for purifying the waste. A closed kiln of 20 tons daily capacity, with rock hoist and gas pump, would cost $10,000. The operation would require 4,800 pounds of coke a day and the attendance of three men on each shift. Figuring interest, depreciation, labor, and coke, the daily cost of CO_2 produced would be $31.90. Neither profit nor loss is figured on the lime. Finally, the quantity of CO_2 would be only about 25 per cent of that required. To produce 80 tons of lime a day would necessitate a correspondingly great outlay and the production of 60 tons of lime for which a market must be found. Manifestly the method does not recommend itself, especially in comparison with the following one.

Second method.—At the plant which has been cited, where 50 tons of straw are used each day, about 80 tons of Brazil (Ind.) bituminous coal are burned every twenty-four hours. This coal contains about 70 per cent carbon. Consequently, 70 per cent of 80 tons, equaling 56 tons, or 112,000 pounds, of carbon are consumed each day. About 12 pounds of air per pound of carbon are necessary for combustion. In the average hand-fired furnace an excess of 50 per cent of air is supplied, making 18 pounds of air per pound of carbon. In the above case there would be 18 times 112,000, or 2,016,000, pounds of air needed. A series of 16 tests reported shows that the per cent of CO_2 in the chimney gases ranges from 8 to 19 per cent. Assuming 10 per cent as a conservative amount, there would be 10 per cent of 2,016,000, or 201,600, pounds of CO_2 available every twenty-four hours from the flue gases. The maximum amount of carbon dioxide needed in the precipitation is twice 19,800, which equals 39,600 pounds. Only 20 per cent of the chimney gases would be needed in the process of purification. Gas pumps capable of delivering 250,000 cubic feet per twenty-four hours, under the pressure of 2 feet of water, would be required.

The cost for gas pump and installation would be $2,500, with no additional attendance above the usual engine-room staff. Figuring cost on the same basis as before, it would amount to $1.35 per diem, as compared with $31.90 in the previous case, a saving of $30.65 a day. The actual cost of producing the necessary lime and CO_2 would be the cost of 10 tons of lime at $5 per ton, or $50, plus $1.35 for pumping, making a total of $51.35 daily.

The cost of installing a precipitating tank and mixing apparatus is so dependent on local conditions that no figures can be given unless the conditions be known. In almost all cases the design could be adapted to the topography, so that it would be unnecessary to pump either the waste, the effluent, or the sludge.

While it is believed that under average conditions filters are not needed, if a higher degree of purification is required at times of very low stream flow than the normal operation of the precipitation tank provides, gravity filters could be employed. Under some conditions a second settling tank, or two precipitation tanks with a reduced rate of flow, might be the more economical. To operate a filter requires an available head of about 3 feet from the surface of the tank. To operate two tanks either in series or in parallel requires practically no additional head.

TREATMENT OF SLUDGE.

Would it pay to treat the sludge in order to recover the lime? Take, for example, the 50-ton mill which wastes 19,800 pounds of lime daily. Assuming an efficiency of 75 per cent in the purification by precipitation alone, there would be present in the sludge 75 per cent of twice 19,800, or 29,700, pounds of lime. Only about 85 per cent of this is recoverable, i. e., 26,700 pounds.

No more economical method of drying the sludge is known than that employed in the manufacture of strawboard itself. Hence the cost may be considered the same. An official of a strawboard company states that the hot rolls receive the pulp from the wet end, press it while it is about 66 per cent water, and deliver it with about 10 per cent of moisture remaining. The cost of removing this 56 per cent of water present is the principal item in the expense of drying. The company estimates that it requires 11 horsepower for twenty-four hours, or 264 horsepower hours, to dry 1 ton of board. If we take 30 pounds of steam as equivalent to 1 horsepower hour, then $11 \times 24 \times 30$, or 7,960, pounds of steam are required per ton of product. If 7 pounds of steam be generated per pound of coal burned, 1,274 pounds of coal are consumed, which, at $3 per ton, makes the cost $1.91 per ton of product. One-half the cake is straw and one-half carbonate of lime, hence the cost per ton of lime present is $3.82.

After the sludge is dried to the consistency of strawboard it would still contain 10 per cent of moisture. To remove the remaining moisture and make the lime available as an oxide the cake must be burned in a limekiln fired with coke, in order that the calcium carbonate shall be reduced to the oxide, thus completing the cycle through which the lime has passed. The cost would be greater than that of burning limestone, because of the greater moisture present. In addition there would be a considerable quantity of the silica present in the ash of the straw. The ash is about 5 per cent of the weight of the original straw, and of this 73 per cent, according to Remsen, will be silica. The major part of the ash would be accumulated waste material unseparated from the lime. It would evidently cost more to recover the lime in the sludge than it is worth.

The particles of straw are so fine that they will not work up into even a second-grade board. In fact, no use for this material has been discovered, hence its waste. The process of manufacture is so very wasteful, then, partly because present methods can not make this finer portion into salable stock.

The question of making a separate product from the sludge was raised. This material contains lime and silica principally. Would it make boards similar to asbestos boards to serve as nonconductors to heat? Whether or not the material, pressed and bonded by cloth, would make a nonconducting article like felt has not been carefully considered.

English patent No. 16966, issued August 6, 1898, covers a process of fireproofing wood or straw by treatment with carbonate of potash, boric acid, sulphate of magnesia, and sulphate of ammonia (see Jour. Soc. Chem. Ind., August 31, 1899, p. 763). The method would not be commercially applicable in this case in view of the ruling prices of felt and asbestos. At present it seems that the only rational way to dispose of the sludge is to run it out on the ground.

CONCLUSIONS.

1. Strawboard waste is an extremely stable substance which does not degenerate when kept in clean containers, but when mixed with other substances of a putrescible nature, such as sewage and other organic matter in streams, it becomes very foul and objectionable.

2. Simple sedimentation is not effective in the purification of strawboard waste.

3. Chemical precipitation appears to be satisfactory from every standpoint except that of cost, which makes it commercially impracticable.

4. Filtration without previous sedimentation is impracticable, but combined with sedimentation is an aid to the process.

5. The sulphates of iron and alumina are the most effective chemical precipitants for the purification of strawboard waste, but so large are the amounts which it is necessary to use that the cost is prohibitive.

6. Lime is of no value as a precipitant.

7. Carbon dioxide has no effect upon the suspended matter in strawboard waste.

8. The combination of carbon dioxide and milk of lime is effective when properly applied, and the process can be economically maintained if conditions are favorable. The results of experiments indicate that 75 per cent of the suspended material can be removed by precipitation with carbon dioxide and milk of lime at high speed of treatment. Higher efficiencies can be obtained at lower speed and by the combination of sand filtration. It is believed, however, that the latter would be necessary only in extreme cases.

SUPPLEMENTARY NOTE.

The objection raised by the officials of the United Box Board and Paper Company to the purification process described in the preceding pages is based upon its cost. It is maintained that the different kinds of box board now upon the market are so evenly balanced in cost of production and competitive selling price that the additional expense incurred in manufacture, which would result from the adoption of this process, would drive strawboard from the market. Nevertheless, it is hoped that the experiments here recorded may stimulate interest in the question considered and aid in directing research that will lead to a satisfactory solution of the problem.

DISPOSAL OF OIL-WELL WASTES AT MARION, IND.

By Isaiah Bowman.

INTRODUCTION.

Since 1886, a date which marks the beginning of the oil and gas industry in eastern Indiana, there has been more or less speculation concerning the pollution of wells and streams in the oil fields in so far as such pollution impairs the purity of drinking water or damages water for domestic and industrial uses. Within the last few years the matter has assumed a more serious aspect. Considerable litigation has resulted from attempts to collect compensation for damages to surface wells by this form of contamination.

In the following pages the manner in which such pollution occurs is shown, and a remedy is suggested for the conditions. The data presented relate to the city of Marion, this city having been chosen as the place of inquiry because it is situated in the center of the oil fields of eastern Indiana and because many cases of well and stream pollution are known to exist there.

Acknowledgments are due to Mr. E. Hulley, superintendent of the Marion waterworks, and Messrs. John E. Weigel and W. L. Benson, well drillers, for assistance rendered by them in preparing this paper.

TOPOGRAPHY AND DRAINAGE OF THE REGION.

The city of Marion is located on Mississinewa River. This stream is tributary to the Wabash and has a length of about 100 miles. The general course of the stream is northwestward, and the channel lies just outside the Mississinewa moraine. Above Marion the river swings against the moraine, cutting steep bluffs into the clay; but near the Arcona bridge, between Eighteenth and Nineteenth streets, it cuts into a gravel terrace formed outside the moraine by the stream when it was overloaded by material derived from the ice which then rested against the moraine. Just opposite Marion-on-the-River, and again near the Washington Street Bridge, the Mississinewa flows over rock. This greatly impedes the dissection of the till plain and terraces in which the river valley has elsewhere been

incised. The difference in the character of the material that the river must remove has resulted in alternate straight and meandering stretches. Each outcrop of rock in the channel is generally indicated by a marked sinuosity of the stream above it.

Back of the river bluffs, which have an average height of about 50 feet, the surface of the country to the southwest is extremely level, and drainage, especially on the flat and wide divides, is sluggish and ineffective. Northeast of the river the Mississinewa moraine gives some relief to the surface, although that part of the moraine near Marion has an average height of not more than 20 or 30 feet.

The valley bottom varies greatly in width. In places it is but little wider than the river, while in the vicinity of the pumping station it is from a half mile to a mile wide. The business part of the city and its more thickly settled portions lie on an old flood plain of the Mississinewa. The oil wells are scattered over the whole region, alike in valley bottom and in the country back of the river bluffs. Occasionally, where the bluffs have a gentle descent, oil wells may be found on them, as well as on the lower surfaces nearer the river, positions which have the advantage of rapid drainage, while the others have the association of stagnant pools of waste oil.

GEOLOGIC FEATURES.

PLEISTOCENE DEPOSITS.

At the place where Sixth street ascends the river bluffs in the western part of the city there is a typical 30-foot section of the till plain. Beneath a covering of till about 10 feet thick is a layer of gravel, which in turn overlies a layer of iron-stained bowlders several feet thick. Below this is a promiscuous deposit of clay and gravel, underlain by cross-bedded and fine-textured sand.

The upper covering of till is persistent throughout this region, varying in thickness from several inches to 15 feet. It is, of course, absent in the valleys where the river has undercut it. Where it is thin it is very porous, because of oxidation and the action of vegetation, so that it offers no obstruction to the free passage of percolating water. Along the present stream channel and over the older flood plain that lies between the bluffs are scattered bowlders which the river has been able to undermine and dislodge from the bowlder bed previously mentioned, but which it is not able to carry downstream. In places the till is so free from pebbles that it is used in the manufacture of brick.

A number of well sections are given herewith, since they represent the character of the glacial deposits, an understanding of which is essential to an appreciation of the conditions of water contamination. The best well section procured in the vicinity of Marion was that

obtained at the pumping station of the city waterworks. At the request of the writer samples of the borings were saved by Mr. E. Hulley, superintendent of the waterworks. The well was drilled in October, 1903. In studying the section it must be remembered that the pumping station is in the valley of the Mississinewa and that the bluff section given above must be added to the well section in order to get a fair notion of the character of the deposits from the surface of the till plain to the rock.

The samples were examined both microscopically and macroscopically. A description of them follows:

Section of well at city waterworks, Marion, Ind.

	Thickness of stratum in feet.	Depth to bottom of stratum in feet.
1. Fine sand and black loam (a peaty deposit in a part of the river channel now abandoned)	3	3
2. Very fine, yellow, sharp, ferruginous sand	28	31
3. Coarse gray sand, the grains being rounded through water action	15	46
4. Fine gravel, made up mostly of erratic material and quartz sand	4	50
5. Pale reddish-brown clay with many stones and considerable gravel, also some iron concretions. The stones and pebbles were of chert, limestone, trap, shale, and quartzite. (Limestone, shale, and chert pebbles seem to have been derived from the underlying rock)	54	104
6. Gray clay, very plastic when wet and containing no pebbles. This clay is remarkably pure and is distinct from the clay bed above it in containing no pebbles whatever in its middle portion, though it merges gradually into the pebbly clay above	26	130
7. Limestone (Niagara). The limestone is water bearing from the top to the last depth given and presumably beyond, but the best supply comes from a subporous and greatly fissured layer 38 feet below the rock surface	58	188

This is a flowing well, the water rising (when the well is piped up) to a height of 18 feet above the surface.

The following boring records were kindly furnished by Mr. John E. Weigel, of Marion, Ind. They show the character and depth of the material overlying the rock at the various places indicated by the corresponding numbers on the accompanying map (fig. 4).

Material overlying rock at certain localities indicated by numbers on fig. 4.

	Feet.
1. Sand and gravel	0–30
2. Sand and gravel	0–17
3. Sand and gravel	0–37
"Blue" clay	37–45
4. Sand and gravel	0–57
"Blue" clay	57–65

	Feet.
5. Gravel	0–50
Mixture of gravel, sand, and clay	50–105
6. Gravel and sand	0–50
Till as in No. 5	50–60
7. Rock in river bottom	0
8. Till, sand, and gravel	0–100
9. Sand and gravel	0–32
10. Sand and gravel	0–60
11. Gravel	0–40
Till	40–100

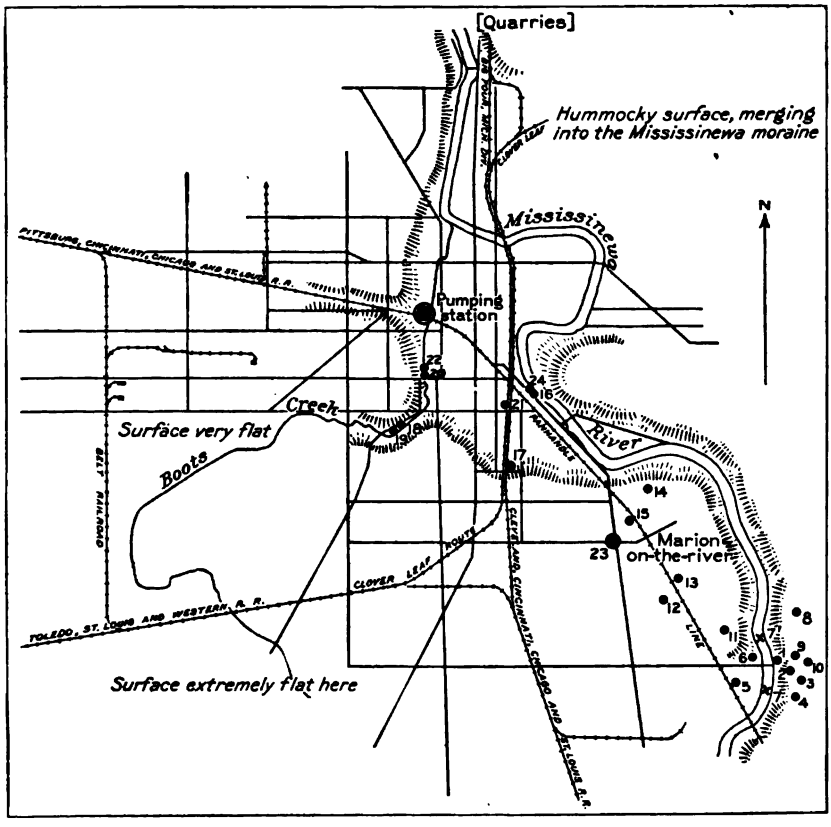


FIG. 4.—Map of Marion, Ind.

12. Till, sand, and gravel	0–200
13. Till, sand, and gravel	0–200
14. Gravel	0–50
Till	50–105
15. Sand and gravel	0–60
Till	60–198
16. Quicksand	0–55
Till (mostly gravel and some brown clay)	55–200
17. Gravel, bearing salt water	0–40
Till	40–177

18 and 19. (The samples previously referred to are from these two wells.)

	Feet.
20. Sand and gravel	0–40
Till	40–50
Gravel	50–70
Clay	70–169
(This well was drilled 118 feet into limestone, making a total depth of 287 feet, but no water was encountered, and the well was abandoned.)	
21. Sand and gravel	0–60
Till	60–117
Gravel	117–127
Clay	127–216

While the last clay bed is extensive, it by no means covers the entire surface of the rock, for well sections frequently show glacial gravel and till all the way to rock. No bowlders are known to occur in it, and the deposit may be nonglacial. Gravel is said to underlie it in places, but none of the gravel was obtainable, and its nature is therefore uncertain.

In the foregoing records no distinction was made between this clay bed and the pronouncedly glacial material overlying it, although an examination of the samples showed that such a distinction exists.

The well sections show that there is an extensive area of rock surface not covered with clay, the entire section yielding only sand and gravel. It also appears that the upper layers of clay, or more properly, of till, and the layers of gravel are in many places differentiated, while in others there is a more or less intimate mixture of these two materials. Such a mixture must not be regarded as impervious to water. There is undoubtedly a more or less free circulation of subsurface water throughout this entire mass of glacial material. This conclusion is warranted not only by a determination of the frequent high porosity of the till and its consequent permeability to water, but also by underground observations on percolating water. In assisting Mr. A. C. Veatch, of this Survey, in work done on Long Island, New York, during the summer of 1903, the writer had occasion, through the kindness of Mr. J. C. Meem, consulting engineer for the Borough Construction Company, to examine a sewer tunnel in course of construction between Sixty-fifth street and Fort Hamilton avenue, South Brooklyn. Different working faces were closely examined, and it was found that even in those places where the till was most clayey in composition the water at a depth of 90 feet from the surface had occupied the pores of the till in such manner and to such a degree that constant pumping was necessary to keep this part of the tunnel dry enough to permit work. The sand and gravel distributed through the till was sufficiently abundant to allow a constant flow of underground water. This fact must be regarded as important, inasmuch as a number of apparently anomalous cases of contamination no doubt depend for their explanation upon this quality of the till.

HARD ROCK FORMATIONS.

The hard rock formations with which this report is concerned are the Niagara limestone, the shales and limestones formerly known as the Hudson River limestone and Utica shale, and the upper Trenton limestone.

NIAGARA LIMESTONE.

Into the Niagara limestone pre-Glacial streams cut valleys several hundred feet deep. This depth was so great that the ice sheet was just able to cover the valleys and divides evenly with drift, and so enable the post-Glacial streams to take an initial course independent of the old rock valleys. The depths to rock at various places in Marion and in the region east of that city indicate that the pre-Glacial drainage was along a northeast-southwest line, almost at right angles to the general direction of the course now taken by the Mississinewa. In some of the deeper parts of this old valley the limestone has been completely eroded and the shale beneath uncovered, while over a considerable area near the bottom of the valley the limestone is but a few feet thick. Toward the divides it becomes thicker, reaching a maximum thickness of about 350 feet at the quarries indicated on the map.

The upper layers of limestone are weathered to a depth of 6 or 8 feet, the result being the formation of a dirty yellow and partially oxidized clay. In most places this clay is porous, usually covering the rock to an insignificant depth. Most of this clay was removed during the advance of the ice. It occurs at the present time only in patches, which furnish all the evidence that is available concerning pre-Glacial conditions.

The limestone lies in nearly horizontal layers. It is extensively fissured, the breaks being more numerous near the top of the section, presumably from pre-Glacial weathering, the weight of the once overlying ice, and the extremes of temperature to which the rock was subjected and the water which it contained. This condition of the limestone permits surface water to have easy access to the rock for some depth, and rock wells and springs (the latter where the rock outcrops in a favorable way) are therefore to be expected. Such springs exist in all the quarries, and the chief source of the city water supply is from wells drilled into the upper limestone rock.

It is maintained by the writer that the water occurring in the upper limestone rock is not derived from some far distant source and transmitted through possible porous layers of limestone, but is essentially of local derivation and is supplied from rainfall percolating through the glacial deposits above. This conclusion is supported by the following considerations:

1. Water must enter the limestone where it is not covered with clay.

2. Once in rock which is fissured and to a slight extent porous, the water must ultimately occupy even those parts of the rock that are covered with clay.

3. The greatest supply of water is found near the top, where the limestone is most highly fissured and where, therefore, the transmission of pressure is most quickly accomplished.

4. The deep valleying which the limestone has suffered and the consequent relation of the superimposed clay beds to the shale and the eroded edges of the limestone prevent the wide distribution of percolating water through possible porous limestone layers.

5. The rock is unevenly fissured. If there is any connection between the fissured condition and the supply from above, we should expect the greatest supply where the rock is most highly fissured; also a considerable disparity in the depths of wells, even though such wells are within short distances of one another. Many examples of the latter condition are found among rock wells.

6. The rock being unevenly fissured and of different degrees of porosity, a combination of unfavorable conditions may result and no water may be procurable from the rock in some places. Such conditions have been known to occur, although the number of cases is rare. One of the most notable occurred in November, 1903, when a boring was made for water by the city waterworks company. On the map the well is indicated by the number 22. The following material was encountered:

Section of dry boring at Marion, Ind.

	Feet.
(1) Sand and gravel	0–50
(2) Mixed gravel and clay	50–169
(3) Limestone (Niagara)	169–287

NOTE.—No water was obtained and the hole was abandoned.

7. So far as the writer has been able to determine, there are no successful wells in the limestone at any depth where the limestone comes very near to the surface, while in the valleys the wells in the rock are scarcely ever unsuccessful and they nearly always flow.

HUDSON RIVER LIMESTONE AND UTICA SHALE.

This group occurs about 365 feet below the surface and is about 560 feet thick, the Trenton limestone beginning at about 925 feet. The shales are somewhat calcareous, and near the top and bottom of the series there are frequent intercalations of bluish thin-bedded limestones. The formation is not water bearing except near the bottom, where water, saline in quality, sometimes occurs.

TRENTON LIMESTONE.

This limestone is dull gray in color, except where it is most calcitic, and there it is nearly white. Oil occurs near the top of the forma-

tion, where the rock is extremely porous. Beneath the oil is salt water, which is pumped out with the crude oil in large quantities. If pumping is continued irregularly the oil well may be permanently injured by the inflow of salt water. In the earlier days of oil wells the driller frequently drilled to too great a depth and the inflow of brine was so strong that the well became useless. In order to form a reservoir for the collection of oil the limestone must be entered some distance, and the most successful wells are those which are drilled deep enough to allow a large amount of oil to collect and still be some distance above the upper level of the brine. The oil wells are usually about 1,050 feet deep, the oil rising to within 600 or 700 feet of the surface.

SOURCES OF CONTAMINATION.

Scarcely a week passes but the boring of an oil well near Marion is completed and the well is "shot" with nitroglycerine. The shooting, no doubt, breaks up the porous Trenton limestone and forms fissures and small caverns, which act as reservoirs into which the oil will flow if this substance occupies the pores of the rock at that place. The surface effect of the shooting is the violent ejection of salt water and oil, often to the estimated amount of thousands of gallons. The oil and salt water sink into the soil, where it is sufficiently porous, and finally reach the surface zone of underground flow, where they partake of the general movement of the water toward the main line of underground drainage.

Wells reaching this saturated zone and lying between the oil well and this line of drainage, or thalweg, become polluted. This takes place even though the amount of oil contributed during a week or a month should be small; for the oil, being lighter than the water and having greater viscosity, is subject to less favorable conditions of lateral flow, and the ratio of the amount of it in the well to the height of the vertical water column of which it forms a part tends to be greater than the ratio expressing a normal condition elsewhere in the saturated zone.

By a similar process of reasoning we are led to believe that the brine, but not the oil, should pollute wells which derive water from deeper zones of flow or from the bottom of the surface zone. This will be true especially where depressions occur in the clay of the drift, or along the main line of underground drainage. This conclusion seems to be supported, in part at least, by the records given elsewhere in this paper, its final justification depending on its accordance with a larger amount of data. The slope of the ground being usually indicative of the direction of flow of underground water, an examination of the surface slopes with reference to a near-by water well should indicate whether or not pollution may arise in a given locality through the circumstances attending the sinking and working

of an oil well. In sinking water wells, depressions in the drift should be avoided, as well as the deeper parts of the valley. As will appear more clearly later in this discussion, however, the burden of responsibility for contamination rests not on the owners of water wells but on the owners of oil wells, for the latter are usually in the field later than the former and locate their wells often with no regard to the rights of others and in contempt of well-established theories of contamination.

If the contamination of wells were due alone to the oil and salt water which is thrown out at the shooting of a well the number of cases of pollution might be much smaller than it is now, for a great deal of the liquid thrown out runs off quickly into the creeks, and only a part of it, except where the surface is level or the ground porous, sinks into the soil. There is another and more prolific source of contamination. The brine and oil pumped from an oil well are delivered to a tank having a capacity of 100 barrels or more. Near the bottom of the tank a pipe leads up at an angle with the side, and it is through this pipe that the salt water is allowed to escape. (See Pl. IV.) A little below the level of the top of the liquid in the tank another pipe leads off. It is through this one that the oil is conducted. The adjustment of these two pipes is made with reference to the capacity of the well, so that but little waste of oil occurs from this source. Some, however, does find its way out of the pipe intended to convey only salt water, and this oil, together with that which is derived from various leaks in the tank and from pumping, result in a constant flow of brine and oil from the well and tank. In many cases the owners of these wells pay no attention to the disposition of this refuse, but allow it to lie in pools or to run slowly over the adjoining fields. Some of it finds its way into the creeks and so into the river, while still another part sinks slowly into the ground. In some cases the attention of owners has been called to the danger of pollution, but only a few of them take the precaution to construct a ditch from the well to the nearest ravine or creek.

It is instructive in this connection to note the manner in which pipes are inserted into the bore holes in rock and the danger of pollution resulting from this method. An 8-inch pipe, called a drivepipe, is driven down through the various materials above the rock as rapidly as the material at the bottom of the pipe can be removed by means of a sand bucket, and is then forced into the upper limestone to a distance of from 5 to 15 feet. With the largest drill that will work in the casing the hole is continued down through the upper limestone as far as the shale overlying the Trenton limestone. Here the size of the bit is reduced, and, after the hole is drilled some distance into the shale, the hole is cased with a 5⅝-inch pipe. The shale itself contains no water, except very small amounts near its base, but the limestone overlying

RECEIVING TANK WITH DISCHARGE PIPES.

it is saturated. It is the effort of the driller to so tightly fit the casing into the shale that no water from the overlying limestone can follow down the pipe to its open lower end. Such a passage along the pipe would either allow the oil to escape upward, or the surficial waters, with sand, clay, etc., to pass downward into the oil, according to the direction of circulation.

The space between the casing and the sides of the hole in the limestone permits such oil and brine as have passed downward through the soil to have easy access to the waters in the limestone. This takes place oftenest where the limestone is near the surface and where the material above it consists wholly of sand and gravel. The water in this loose material will tend to move nearly vertically downward, but contamination will occur with almost equal certainty where the direction of movement has a strong horizontal component, the wells being so numerous and crowded that the refuse from one readily contaminates the water in the rock adjacent to others. In the vicinity of the Thirty-eighth Street Bridge the water table stands from 30 to 35 feet below the surface, showing that the movement of whatever additions it may be receiving by downward percolation from the surface must be nearly vertical, as evidences of lateral movement, as expressed by any rise of the water table, are absent. The water level in the rock at this and similar places seems to supply additional proof of the local sources of the water. The flowing wells in the valley are at least 50 or 60 feet lower than those about Thirty-eighth Street Bridge, and the height to which the water will rise in the strongest of the flowing wells seems to be always somewhat less than the height of the water level in adjacent areas. Precise levels run to the various wells would furnish data of great value in settling questionable points of this nature.

Where artesian effect is pronounced pollution from the source under consideration may not be accomplished as readily, though it seems that in time the inflow of salt water near the head would contaminate most of the water in the rock. The likelihood of such an occurrence is being strengthened continually because of the constantly increasing number of oil wells. The water from many rock wells shows at the present time an extremely high percentage of chlorine, and it is quite possible that it is now derived from that source, though, because of the relatively small amount delivered, diffusion does not allow the result to be so noticeable as it may in time become when the supply is increased.

It has been shown before that a differentiation of the refuse from an oil well may be expected to take place, the oil remaining undiffused and comparatively near the surface, while the salt water sinks down until diffusion destroys the disparity existing between the specific gravities of the brine and the water derived from rainfall. There is, therefore, more danger arising from the complete contamination of

wells near the surface by means of oil than in the case of deeper wells from brine. This is true especially where the water table is lowered through excessive pumping. Any oil near the surface will be induced to assume lower and lower levels until, as pumping increases, it is drawn into the pipe. The example of this occurrence quoted below is all the more interesting when it is known that the above deduction was reached before examples of this sort of thing were known.

"On December 1," writes Mr. Hulley, "the water wells [24 on the map] of the Indiana Brewing Association, at Marion, began pumping oil. They are 160 feet deep and in gravel. They are flowing wells, but the flow not being sufficient, pumping by means of air lift is resorted to. When the amount of oil in the water becomes too great the pumps are stopped, and after standing for some time, so that the wells begin to flow, oil ceases to occur in the water. When pumping is resumed no oil is noticeable until the water level is lowered considerably through pumping." Mr. Hulley says further that the oil is without odor, showing that it has been purified by passing through sand and gravel and that it has evidently gotten into the ground from some distant source, as there are no oil wells near by.

There are thus seen to be two chief sources of danger of contamination. Oil and brine may escape between the casing and the shale and, rising to the porous or fissured layers of limestone, may contaminate the water therein, or they may sink down through the soil from stagnant pools of refuse at the surface. The danger arising from the former source seems to be very small, for, considering the height to which the oil will naturally rise and the fact that the oil wells are frequently not pumped for a day or two, the return of the oil from the outside of the casing into the well would be accompanied by an inflow of sand which would be destructive to the well. This is probably but seldom the case. Where wells have been sand choked it has not as yet been definitely proved whether the source of the sand was from above or below, the difficulty being that in both cases it would be derived from limestone. Until this danger has been proved to be actual no regulation by law will or should be attempted.

Regarding the latter source of danger, from water seeping through the soil from above, there is pretty conclusive proof. Moreover, the evil effects of the condition are so widespread and the remedy is so simple that the disposition of oil refuse should be made a subject of legislative enactment. In the country districts there is little need for vigilance beyond securing the quick removal of oil refuse to the nearest stream by means of ditches and the intelligent selection, with reference to the probable movement of the underground water, of sites for oil wells. It is in the thickly settled parts of the State, in villages and cities where water wells are more numerous, and where they can not always be properly located, that the need for a remedy is most

urgent. The oil wells are, as a rule, yielding a lavish return to their owners, and there is no reason why these owners should not be compelled within proper limits to join in the construction of sewers which will convey oil refuse to the river.

The streams in this region are all more or less polluted, the water having an exceedingly unpleasant odor and a yellowish-white color. This is the color of the brine as it is pumped from the wells and is due to the presence of sulphur. From time to time public interest is aroused by the unsightly condition of the streams and there is much discussion in regard to the disposition of the water. In Marion the discussion centers about Boots Creek, for it is this creek which runs through the city and is thought to endanger health. At the present time there is under consideration the building of an aqueduct for the transportation of this water to the Mississinewa.

Regarding the healthfulness of these streams, it is noteworthy that before the beginning of the oil and gas industry they were so sluggish that in the dry season, when they were a mere succession of pools, the stagnant condition of the water, aided by the addition of sewage and foul vegetable matter, resulted frequently in typhoid fever, while at the present time, owing to the steady contributions from oil and gas wells, there is active circulation of water throughout the entire year.

Dr. W. A. Fankboner, of Marion, has this to say about the condition of Boots Creek: "Its condition now is more healthful than before oil refuse was turned into it. To be sure, to some people the odor is unpleasant, but the stream is not overgrown with weeds and covered with slime, as it formerly was at certain times of the year; and the oil has made it unpleasant as a breeding place for mosquitoes." He also says that there is no ground for the charge that more cases of typhoid fever have occurred along this creek than along other creeks but slightly polluted.

The consideration of all the foregoing possibilities, together with the fact that the city of Marion depends for its water supply upon rock wells (the surface wells not supplying an adequate amount), makes the danger seem very grave.

There are at least 75 oil wells in a few square miles of territory near Thirty-eighth Street Bridge, where clay does not overlie the rock. The amount of oil refuse that finds its way into the limestone is enormous, 200 or 300 surface and rock wells in this area, according to Mr. Weigel, suffering contamination, and unless this refuse is drained off into the river and not allowed to sink into the soil the gravest fears may be entertained for the continued purity of the city of Marion's water supply. A number of these wells were visited and the water examined. Among them were those belonging to Doctor Snodgrass and Messrs. Vansky and Keene. The location of these three wells is indicated on the map by the number 23 (p. 39). In other

places, where clay overlies the rock to some thickness, the present danger may not be so great, although ultimately, because of the nature of the source from which all the water in the upper limestone is derived, the water will become contaminated even at these places.

With reference to this point, it has too long been the custom to make light of a situation that in a year or so may become very grave. Deeper sources of good water are unknown in this part of the State. The shale beneath the Niagara limestone yields practically no water, the little it does yield being saline, while still deeper is the Trenton limestone, full of oil and brine. Neither can the water from the streams be utilized, the constant inflow of brine and oil from adjacent oil wells rendering this plan impossible. Here practically the single source of the water supply of 27,000 people is threatened, and yet no adequate interest is aroused and no means are taken to prevent the danger.

The plea has been made that it is a necessary evil. The recent epidemic of typhoid fever at Butler, Pa., was due to just as "necessary" an evil, but that outbreak not only made the so-called necessity appear diminutive but made the neglect of such conditions seem criminal. It is not inferred that the same disease will follow the contamination of water through oil and brine, but it is inferred and emphasized that the discomfort and expense attending such contamination and the consequent lack of pure water may result in evils quite as great.

It is not sufficient to begin a study of remedies after mischief has been done. If even the probability of pollution of city water is proved, prompt means should be taken to prevent such pollution.

SUPPLEMENTARY NOTE.

By Marshall Ora Leighton.

To carry oil-well wastes as directly as possible into running streams of water in accordance with the plan recommended in the preceding pages for the relief of ground-water supplies from pollution by oil and brine involves the direct pollution of the streams to an extent even greater than they are now contaminated in the oil fields. The question immediately presented is whether it is better from an economic standpoint to preserve local ground waters at the expense of surface waters which in flowing downstream affect wide areas, or to conserve the interests of many riparian owners below and, so far as may be possible, to retain these wastes in the immediate localities from which they are derived. It may be argued that any locality in which oil wells are developed has, by reason of that development, such extraordinary ecomonic advantages that it may well afford to suffer for any incidental loss which may arise from waste oil and brine. And is not the pecuniary advantage which follows the discovery of oil entirely compensatory for the loss of water resources? On the other hand, if the polluting matter is turned into the streams it destroys the value of water to lower riparian owners, who at common law have a right to that water in its purest natural state. The result of such procedure would be to relieve the fortunate oil region from an unfavorable feature which it is amply able to bear—in other words, to enable it further to enrich itself at the expense of districts that are unaided by the presence of oil deposits. Yet with reference to the other side of the question, it may be said that if all possible precautions were taken to hold oil and brine waters within the oil regions there would still be a pollution of rivers nearly if not quite as complete as would arise from carrying out the plan suggested by Mr. Bowman. There is no doubt that where oil deposits are developed stream pollution is inevitable. The rain which falls upon the earth will carry with it oil and brine which it encounters on the earth's surface. In addition to this, the percolating water will reach the lowest level, and whether this water be rain or oil and brine the streams will still be polluted.

On the other hand, the people living in the oil regions must have sweet water for domestic purposes. This is a necessity which transcends all other economic demands. As shown in Mr. Bowman's discussion, the rivers in the Marion region are already unavailable as sources of pure water supply, and the only supply remaining is ground water. Therefore, as we can not save the stream and can save the ground water, there appears to be no question concerning the wisdom of accomplishing the latter end. Stream pollution in this case, as in certain others, is a part of the price paid for the accumulation of natural wealth. It can be considered an inevitable loss with equanimity, as it is only a temporary loss. Oil fields in time become exhausted and in due season the rivers will regain their pure condition. It would require an incomparably longer time to redeem an oil and brine besodden earth.

All things considered, the recommendations set forth in the foregoing paper seem to be the wisest and most expedient that present themselves at the present time.

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OF

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MYRON L. FULLER
GEOLOGIST IN CHARGE

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., May 11, 1904.

SIR: I have the honor to transmit herewith a manuscript entitled "Underground Waters in Eastern United States," which I would recommend to be published in the series of Water Supply and Irrigation Papers.

The aim of the paper is to present a brief summary of the underground water conditions in the States east of the Mississippi and in those States bordering that river on the west. It is prepared to meet the demand of drillers and others for general information relating to the broader features of the occurrence of underground waters in the various States or districts.

The report includes papers by twenty geologists and embraces discussions of the conditions in each State and of the general occurrence of underground waters as a whole.

Very respectfully, F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

UNDERGROUND WATERS OF EASTERN UNITED STATES.

M. L. FULLER,
Geologist in charge.

INTRODUCTION.

By M. L. FULLER.

The present paper is a brief summary of the underground water conditions in eastern United States, prepared to meet the demands of drillers and others for information relating to the general water resources of the various States or of specified regions.

The detail with which the several regions or subjects are discussed depends mainly on their relative importance, although because of the greater amount of work done in certain localities, or on certain problems, it is possible to make more complete and definite statements in regard to the underground water supplies in some regions than in others. The included reports have been prepared by a number of geologists, each, in general, having charge of the investigations in a particular State or group of States. Because of the number of contributors there is necessarily considerable variation in the manner of treatment of the subject, but in most cases the same general plan has been followed.

In preparing the paper simplicity of treatment has been kept in mind, and elaborate geologic discussions have been omitted. Wherever possible maps have been given in preference to long and possibly obscure discussions. In some instances, however, it has been necessary to describe the various water-bearing formations under their geologic names. Where this has been necessary the aim has been to employ those terms which are oldest and best known to the people of the States to which the discussion relates.

For the purpose of presenting in a simple manner a few of the more important features relating to the nature and occurrence of subterranean waters and of making more intelligible the descriptions of the conditions in the various States, there is given a short paper on the general occurrence of underground waters.

OCCURRENCE OF UNDERGROUND WATERS.

By M. L. Fuller.

SOURCES OF GROUND WATER.

In general those who have written on underground waters have stated that rainfall is the only source of underground waters. In reality, however, while rainfall probably contributes at least 99 per cent to the total subterranean water, there are several other possible sources of such water.

It is a well-known fact that in coral and other islands of porous material, such as sand and gravel, especially where the rainfall is light, the sea water penetrates through the pores of the rock for a considerable distance inland. Where the rainfall is heavy the salt water may be displaced to some depth by fresh water, but the downward penetration of the fresh water must be necessarily limited. In other instances sea water is known to penetrate along solution passages or caverns into the interior of limestones, and at Cephalonia, in Greece, a stream of salt water leaves the sea and, passing inland, finally disappears into porous limestones.

By far the larger portion of the sedimentary deposits, including sandstones, shales, limestones, etc., were originally laid down along the borders or beneath the surface of the ocean and were, of course, originally saturated with salt water. It is probable that this water was often retained in the materials when they became consolidated into rocks, and is represented by the salt water now found at great depths in many of the wells drilled for oil and gas, in which it is not uncommon to encounter, after passing through many hundred feet of entirely dry rock, porous beds filled with salt water, possibly accompanied by gas and oil. It is claimed by others, however, that the salt waters are not originally included portions of the sea, but are surface waters which have become charged with mineral matter which they have dissolved in the course of their passage through the rock.

Practically all volcanic rocks contain water when they are erupted at the surface and all eruptions are accompanied by discharges of large amounts of steam. The occurrence of this water has been accounted for in several ways. It may have been originally included in the rocks which were melted to form the lava, or it may represent water which

has penetrated downward through fissures and come in contact with the molten lava on its way to the surface.

AMOUNT OF RAINFALL.

The rainfall in the eastern United States is abundant, and although only a portion of it is absorbed by the earth and becomes a part of the subterranean stores, the amount is sufficient to furnish ample under-

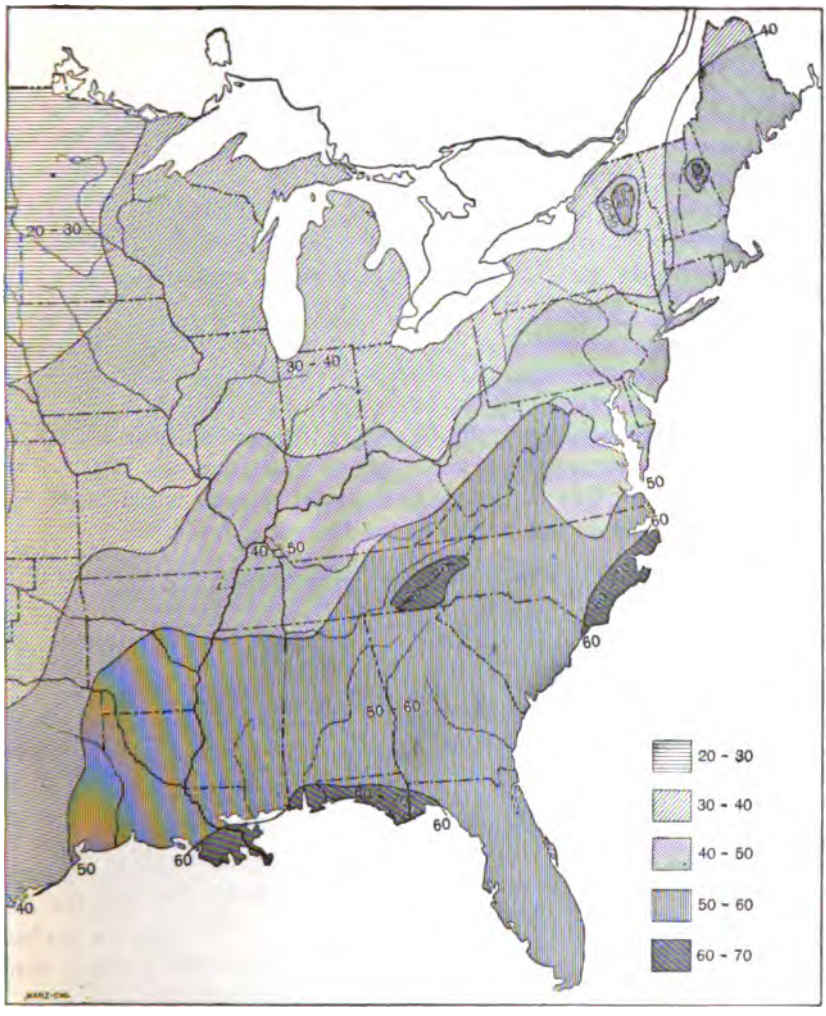


FIG. 1.—Rainfall map of eastern United States. Figures represent inches of annual rainfall.

ground supplies for a large proportion of the inhabitants. The average rainfall varies from 20 to nearly 70 inches, the lowest being in the extreme northwestern portion of Minnesota. Rain to a depth of over 60 inches a year falls on the Mississippi delta below New Orleans and along the Gulf coast from near Mobile, Ala., to Tallahassee, Fla.

Similar amounts fall in the higher mountains of western North Carolina and eastern Tennessee, along the coast of North Carolina, and in the Adirondack and White mountains. In the Gulf and South Atlantic States the rainfall is between 50 and 60 inches; in the New England, Central Atlantic, and Ohio River States, between 40 and 50 inches; in the Upper Mississippi and Great Lakes States, from 30 to 40 inches, while in northwestern Iowa and most of Minnesota the rainfall is only from 20 to 30 inches.

DISPOSAL OF RAINFALL.

The rainfall is removed from the surface principally in three ways: (1) By evaporation; (2) by run-off through the streams, and (3) by absorption into rocks and unconsolidated deposits.

Evaporation.—Evaporation, although far less conspicuous than the other methods of removal of the water, is, nevertheless, one of the most important. The amount evaporated depends on the temperature and the relative dryness of the air, and commonly amounts to one-half or more of the total water falling as rain. Locally, evaporation is dependent to a considerable extent on the density of the vegetation, but when broad areas are considered the amount of vegetation has a less conspicuous effect on the total evaporation.

Run-off.—The amount of run-off is dependent partly on evaporation and partly on the nature of the materials on which the rain falls. The proportion of run-off or discharge to the total rainfall is indicated for the Mississippi and its tributaries in the following table:[a]

Proportion of run-off to rainfall in Mississippi basin.

	Per cent.
Ohio	24
Missouri	15
Upper Mississippi	24
Small tributaries	15
Arkansas and White	15
Red	20
Yazoo	90
St. Francis	90
Entire Mississippi system	25

The run-off of streams in New England is considerably greater. With a rainfall which averages from 40 to 50 inches the run-off of a number of streams is as follows:

Proportion of rainfall to run-off in New England.

	Inches.
Kennebec	22.4
Androscoggin	24.2
Merrimac	21.3

Absorption.—The rainfall that is not removed by evaporation or by the surface streams is absorbed by the soil or rocks with which it comes into contact, either directly or after being gathered into streams.

[a] Humphreys and Abbot, Phys. and Hydrol. of Mississippi River, Washington, 1861, p. 136.

A. SINK-HOLE CONNECTION WITH UNDERGROUND DRAINAGE SYSTEM.

B. UNDERGROUND CHANNEL.

Absorption takes place both directly and indirectly. In the case of direct absorption the rain falls upon the surface of the rock and the water is absorbed either by its pores or by the fissures or cavities which it may contain. In indirect absorption the water is first directly absorbed into loose unconsolidated deposits overlying the solid rocks, or is gathered into streams flowing over their surfaces. In those cases where the rocks are directly exposed to the rainfall the water which is not immediately absorbed runs off and either enters loose materials or is gathered into the streams as indicated. The unconsolidated materials soon become saturated to a certain level, and the rocks upon which they lie are in this way kept constantly in contact with the water, which is continually absorbed.

In the case of the water entering the sands and gravels the direction of the movement is generally toward the river rather than away from it, but in arid regions, where the rainfall is slight, waters are often absorbed by the gravels from the streams which have come from regions of greater rainfall. The relative amount of water indirectly absorbed by the rocks is far greater than that directly received through rainfall.

PERMEABILITY AND STORAGE CAPACITY OF ROCKS.

Methods of absorption.—The amount of water which enters the rocks or other materials by direct absorption varies greatly with the nature of the materials. The amount absorbed by the porous beds of

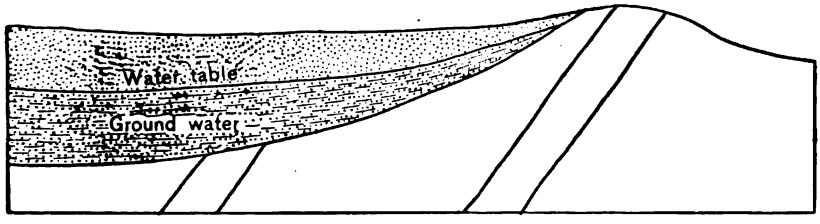


FIG. 2.—Absorptive conditions of outcrop.

sands and gravels that occur along stream valleys and along lake shores and the coast is very large. In some regions, as in portions of Cape Cod and Long Island, there are practically no surface streams, the water being absorbed by the soil as soon as it falls and carried to the sea by underground drainage.

Next to unconsolidated deposits, the rocks which present the conditions most favorable for direct absorption are the sandstones and certain of the porous limestones. In the case of the granites, slates, and other massive rocks the direct absorption is very slight.

Besides the character of the material, the amount of absorption depends very largely upon the inclination of the porous beds, the amount being much greater in the gently inclined beds than in those

having steep dips. Thus in fig. 3 the two beds represented as outcropping on a level surface present widely different absorptive conditions owing to the difference in area of their absorptive surfaces, the exposed surface of the gently sloping bed (*a'*—*b'*) being several times greater than that of the highly inclined bed (*a*—*b*).

FIG. 3.—Relation of areas of outcrop to dip.

Bedding planes.—Bedding planes are the surfaces separating beds of stratified rock. Where the character of the rock changes, as it frequently does along these bedding planes, the conditions are generally very much more favorable for the passage of water than elsewhere in the rock. The same is true in igneous rocks where two types of rock come together.

Solution caverns.—In a few instances waters enter the ground as definite streams through caverns or other passages formed by the solution of limestone and other similar rock. One of the most commom methods by which water enters the limestones is by means of the depressions known as sink holes. These sinks are due to the caving in of underground caverns which have previously been formed by underground streams. A connection is frequently maintained through these sinks between the surface and the underground channels, and the waters falling on the surface flow into them and pass downward to join the underground supplies. Pl. I, *A*, shows such a sink, while Pl. I, *B*, shows an underground channel in soluble rock.

Faults.—A fault is a plane or fracture which cuts the rocks and along which movement has taken place, resulting in the displacement

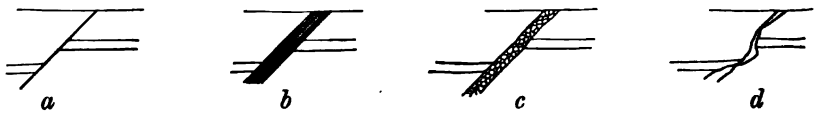


FIG. 4.—Common types of faults.

with relation to one another of the rocks on the opposite sides. Sometimes the fault consists of a single plane, with solid walls on either side, as indicated in fig. 4, *a*, but in many cases there are really a number of parallel planes, very close together, along which slipping has taken place. In such instances the rock on either side has the sheety appearance indicated in the cross section, fig. 4, *b*. In other cases the rocks on either side of the fault plane are completely crushed and the fragments more or less disturbed with relation to one another. In still other cases the fractures are irregular, and the movement of the rocks has been such that projecting points come opposite one another, leaving intervening cavities, as shown in fig. 4, *c*.

A. OUTCROP CUT BY JOINT OPENINGS.

B. CLEAVAGE IN SLATE.

The conditions for the passage of water are least favorable in the case of a single definite fault plane. In the sheeted type of faulting the conditions are somewhat more favorable, as there are more surfaces along which the water can penetrate. Along the crushed zones the open spaces are frequently very considerable and permit the passage of large amounts of water. In the case of an irregular fault plane, as in fig. 4, *d*, the conditions are less constant, but in general such a fault will permit of the passage of considerable amounts of water.

Joints.—Joints are smooth fracture planes cutting the rock in various directions. They differ from the faults in that there has been practically no motion of the rocks bordering the plane. They therefore correspond most nearly to the single fault plane described above, and likewise present relatively unfavorable conditions for the passage of large amounts of water. At the same time water in moderate amounts very frequently passes along such planes, especially along the line of intersection of two or more planes. Pl. II, *A*, illustrates an outcrop of a rock ledge cut by joints in two directions and presents conditions favorable to the absorption and downward passage of water.

Cleavage.—Cleavage is the name applied to the minor planes cutting the rock. Unlike the joints they usually run in only one direction, and are frequently not actual fractures, but are simply lines along which the rock would tend to split under favorable conditions. Cleavage is best devoloped in fine-grained compact rocks of which the well-known roofing slate is the best example. Pl. II, *B*, shows a number of these cleavage planes in a ledge of this material. Cleavage does not afford as ready a passage for the water as the other features described.

Foliation and schistosity.—Foliation and schistosity are features due to the occurrence of the minerals of the rock in thin plate-like crystals parallel to one another. The arrangement is such that in many instances water passes with some readiness into the rock along the planes formed by layers or laminæ of these crystals.

Porosity.—Porosity is the term given to designate the amount of pores or open spaces between the particles of which the rock is made up. In a general way porosity is determined by the amount of water which the rock is capable of absorbing. The amount varies greatly, being least in the compact igneous rocks and greatest in sandstones and loose sand. In the following table are given the amounts of water which a cubic foot of sand and some common rocks will absorb:

Material.	Water absorbed per cubic foot.	Material.	Water absorbed per cubic foot.
	Quarts.		*Quarts.*
Sand	10	Dolomite	1–10
Potsdam sandstone	2–6	Chalk	8
Triassic sandstone	4	Granite	$\frac{1}{100}$–$\frac{1}{4}$
Trenton limestone	$\frac{1}{4}$–$1\frac{1}{4}$		

Pl. III shows the appearance of two sandstone fragments under the microscope. The black portions in these sections represent what were originally open spaces between the grains.

OCCURRENCE AND AMOUNT OF GROUND WATER.

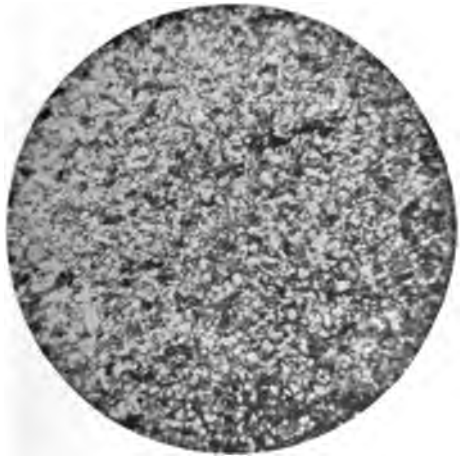
Occurrence.—The underground water which has been derived in the various ways outlined above occurs in the rocks under a variety of conditions. A part occupies the spaces along the bedding, fault, joint, and cleavage planes and a part occurs in the solution channels and caverns dissolved in the soluble rocks. The various fracture planes indicated, while very numerous in the aggregate, nevertheless comprise but a very small proportion of the open spaces within the rock, as they are limited to plane surfaces. The pores, or spaces between the particles which make up the rocks, are, on the contrary, everywhere present throughout the entire mass and constitute by far the larger proportion of the open space in the rock.

Amount.—In general, it is necessary only to penetrate a few feet of strata to reach a zone saturated with water, the depth depending upon the amount of precipitation, being least in regions of much rainfall and greatest in arid regions.

The downward limit of penetration of the water is dependent upon a variety of causes. It is frequently assumed that all rocks are saturated to great depths, the limit to which the water will penetrate being assumed to be that point at which the weight of the rock becomes so enormous that pores between the particles can not exist. This limit has been placed at about 6 miles. Practical experience in well drilling, however, shows that the assumption that all rocks are saturated below a moderate depth is far from being substantiated. In the Pennsylvania and New York oil regions, for instance, it is a very common experience to encounter, at a depth often of only a few hundred feet, rocks which are practically destitute of water. These include coarse-grained open sandstones, capable of holding large amounts, yet as far as can be determined they are absolutely dry, it being necessary in many instances to pour in from the top the water necessary for the process of drilling. In some instances after passing through these water-free rocks salt waters are encountered, but it is very rarely the case that fresh waters are found below the dry series. In some instances wells have been drilled several thousand feet without encountering any water whatever below the first few hundred feet. Although the rocks are far from being saturated, slight amounts of moisture are doubtless held in the pores.

Notwithstanding the fact that the depths to which the waters penetrate in quantities are probably much less than is frequently assumed, there is, nevertheless, an enormous amount of ground water. It has been estimated that the average pore space of the surface rocks is

A



B

SANDSTONES VIEWED UNDER THE MICROSCOPE.

about 10 per cent of their volume, but 5 per cent will probably be found to be more nearly correct.

WATER-BEARING FORMATIONS.

All rocks contain more or less water which, as pointed out, occupies either cavities in the rock or occurs between the minute pores. The water which occurs in the pores is given up readily only in the coarser rocks, such as sandstones, the fine-grained rocks yielding very little of such water when penetrated by the drill. In these rocks, the water, when found, usually comes from the joint, fault, or foliation planes. The conditions of the occurrence of water in the various rocks are very variable and are described in the following pages.

Sand and gravel.—Sands and gravels are very porous, 30 per cent of their volume frequently being made up of free space between the grains. In such materials the whole mass is saturated with water below the water level, and when penetrated by wells copious supplies are quickly yielded. The waters are generally of good quality, but are sometimes somewhat mineralized, the material being derived from the more soluble fragments and particles which constitute the deposits.

In passing downward through the sands surface waters are subjected to natural filtration, especially in the finer varieties, and the substances with which they may have originally been polluted are frequently removed. In the coarser types of sand, and in gravel, the water passes downward more rapidly, the conditions are less favorable for filtration, and the waters may remain polluted. In general, however, waters from sand and gravels, if taken from a considerable distance below the surface, are safe to use.

In the sands and finer gravels the cheapest and best method of obtaining water is by driven wells, which can be sunk quickly and at a very slight cost. In the very fine sands or quicksands, however, it is very difficult to exclude the material from the pipes, the quicksand frequently penetrating the well and clogging the pipe or ruining the pump. Because of the readiness with which sands and gravels yield their water, wells located close together frequently affect one another, the lower well or the wells which draw from the sand at the lowest points drawing the water from the higher wells. The readiness of movement of the water is also the cause of important fluctuations of level of the surface of the saturated zone, the water level often falling rapidly after wet seasons. To secure permanent supplies the wells should penetrate to the level which the water surface occupies in the driest seasons.

Clay.—Clay is very impervious to water, and in itself contains little or none which can be utilized as a source of supply. Water, however, is frequently reported in clays, but usually comes from more or less sandy layers. In some cases sand which approaches clay in

fineness, and which is sometimes mistaken for clay, yields considerable amounts of water. Clay is of the greatest importance, not as a water-bearer but as a confining layer to porous sands, from which it prevents the water from escaping. The waters of clays, because of the fineness of the material, come into contact with relatively large amounts of mineral matter and frequently become mineralized, lime and salt being the most common substances dissolved. The waters of clays are, as a rule, free from contamination. When, because of the absence of other sources, it is necessary to obtain supplies from clay, a well should be sunk with as large a diameter as possible and continued beneath the point at which the water is obtained to a sufficient depth to furnish ample storage capacity, as clay waters are slight in amount and are yielded very slowly. Dug wells are usually most satisfactory where the clay is near the surface, but such wells should be carefully covered and guarded from all sources of pollution (see fig. 5).

Till.—Till is a heterogeneous mixture of clay, sand, gravel, and bowlders, deposited by glaciers in the northern portion of the country. In texture it varies from porous to impervious according to whether sand or clay predominates. It is seldom definitely bedded. The water generally occurs in small more or less tubular channels a few inches in diameter, but occasionally is distributed through interstratified sandy beds.

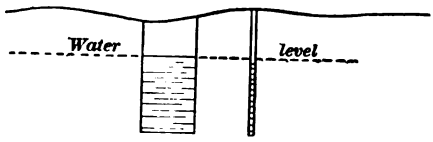


FIG. 5.—Relative size and storage capacity of dug and drilled wells.

In the aggregate the till yields a large amount of water, being the source of supply in the rural districts at a great number of points throughout the entire northern portion of the country. Because of the occurrence of the water in definite channels, however, the success of wells varies greatly. In general, wells of large diameter, similar to those described in the preceding paragraph, give the best success. Fig. 5 represents two wells of the same depth, one of the dug type and one of the bored type. It will be seen that in the well of the dug type not only is a larger amount of material encountered in cross section, but that the area of surface from which water can enter is many times greater than in the well of the bored type. The open well also presents larger storage possibilities, it being thus possible to utilize small supplies, which would be insufficient in the case of the bored well.

The water of the till is generally uncontaminated because in its downward penetration through the clay of which the till is in part composed it is subjected to natural filtration. If the water becomes polluted, however, it may retain its dangerous character for a long period of time and for considerable distances.

Sandstone, conglomerate, and quartzite.—Sandstone is on the whole the best water-bearer of the solid rocks. Under the most favorable conditions the rock is saturated throughout its extent below the regular ground-water level, and water is yielded wherever the sandstone is struck by the drill within these limits. The water is yielded freely as a rule, although in some of the finer-grained sandstones it flows less readily. In quality the water averages better than in any other material except sand and gravels. It is almost never polluted, and wells can generally be safely used if they are cased to keep out the surface waters. The drilled type of well is utilized except where the sandstone is very near the surface.

Conglomerates sometimes furnish considerable water supplies, although as a rule their absorptive powers are not so great as those of sandstones, and they are much less frequently encountered. Quartzite is a sandstone in which the spaces between the grains have been filled by hard, siliceous matter. Because of the filling of the pores by this material there is relatively little chance for the water to enter, and the rocks are not commonly an important source of water.

Slate.—Slate, like clay, is a poor water bearer, but may yield water from bedding, joint, cleavage planes, etc. Its most important use, however, is as a confining layer to prevent the escape of water from porous sandstones which may be interbedded with it. The waters are reached by deep wells and are generally uncontaminated.

Limestone.—The waters of limestone occur mainly in open channels, caverns, etc, dissolved in the rock by the water itself. The water originally probably followed joint or bedding planes, which were gradually enlarged by solution into the caverns which we now find.

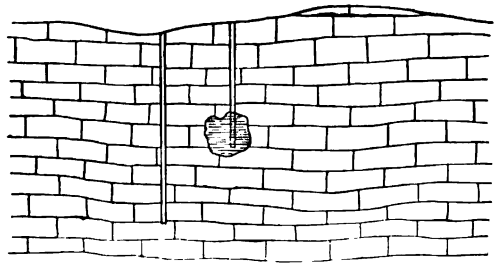


FIG. 6.—Difference in conditions of adjacent wells in limestone.

The occurrence of caverns and passages within the limestone is very irregular and their location can seldom be predicted. Most deep wells, however, which are drilled in limestone regions encounter one or more such passages at a relatively slight depth from the surface. Wells, even where only a few feet apart, nevertheless often obtain very different results, as a difference of a foot or two frequently means the missing of a certain channel, as indicated in fig. 6. The waters are generally hard, but are not commonly otherwise mineral-

ized. There is, however, a considerable likelihood of pollution, due to the fact that much of the waters of the underground streams in the limestone have found their way downward through sink holes, carrying with them more or less surface wash (see Pl. I, *A*).

Granite, gneiss, and schist.—The granites and gneisses are very dense and possess very small pore spaces, and the body of these rocks hold very little water. In schists, however, considerable water often pene-

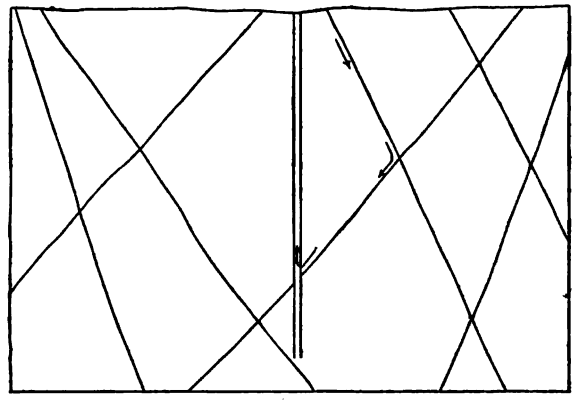


FIG. 7.—Well in jointed rock.

trates along the foliation planes and is held by the rock, but such water is given up very slowly and is not of importance as a source of supply.

It is along the joints that the largest supplies are obtained. These joints are most common near the surface and diminish in number and in definiteness as depth increases. For this reason the water supplies, if obtained at all, are generally found within 200 or 300 feet of the surface. It is generally useless to go deeper than 500 feet for waters in these crystalline rocks, although in some instances, as at Atlanta, water supplies have been obtained at depths as great as 1,600 feet. The joints generally occur in complex systems of intersecting planes, and it is possible for polluted water starting very near the mouth of the well to pass in a zigzag course downward along the joints, finally reaching the well at a depth of many hundred feet (fig. 7), as was the case in a well at Atlanta, Ga., which finally had to be abandoned. For this reason wells drilled in igneous rocks in cities and other thickly populated regions are liable to become polluted. Waters from such wells, if they are to be used for drinking purposes, should be tested occasionally to determine the possibility of pollution.

TEMPERATURE OF UNDERGROUND WATERS.

In all wells there is a certain depth, which differs in different localities, at which there is practically no difference in the temperature of the water from season to season or from year to year. This is known

as the normal temperature of the water for a given region, and it agrees very closely with the mean annual temperature of the same locality. The depth of uniform temperature varies somewhat in different localities, but is commonly from 50 to 60 feet below the surface. The temperature varies from about 40° or 45° in New England to about 65° or 70° in the Gulf States.

Waters occurring nearer to the surface than the zone of uniform temperature vary in temperature according to season, being warmer than the normal in summer months and colder in the winter months. The temperature of waters warmer than the normal may also be due to the great depth from which the waters have come.

The main cause of rise in temperature below the line of invariable temperature is the internal heat of the earth. This internal heat increases rapidly downward, the rate of increase varying from 1° in 30 feet to 1° in 100 feet, the average increase being about 1° to 50 feet. The temperature of the water is very little affected in passing through the upper 50 feet of its course, hence its temperature is a fair indication of the depth from which it is derived.

Besides the internal heat of the earth the heat of igneous masses below the surface of the earth has been thought to give rise to the hot springs of many localities, and in some instances the heat evolved by the chemical decay of rocks has been cited to explain the temperature of hot springs.

RECOVERY OF UNDERGROUND WATERS.

Water is returned to the surface in three general ways: (1) By seepage, (2) by springs, and (3) by wells. A brief discussion of each method is given in the following pages.

SEEPAGE.

Although a relatively obscure method, seepage is of great importance in returning water to the surface, especially in sands and gravels. Seepage water does not occupy definite channels, but fills the pores between the component grains of the various surface or other deposits. It emerges at the surface whenever the water level within the deposits becomes, through additions from rainfall, etc., higher than that of the lowest depressions or level of the surface. Sometimes, as on the south side of Long Island and elsewhere, the waters seep out from the sands over extensive areas along the shores a few feet above sea level. In such places the water frequently does not gather into definite channels, but forms more or less extensive fresh marshes, and gradually works its way into the sea. More frequently, however, seepage waters emerge in stream channels and other depressions. In some cases the water enters the stream at or just above the surface, but in most

instances the main supply enters below the water level along the sides and bottom of the channel.

The distinction between seepage and springs is not sharp. The term "spring" is usually limited to those occurrences where the water comes out at a definite point, or at least emerges from a restricted area, but water that often appears at the surface as general seepage is often found, on excavating at its point of emergence, to come from a definite channel, and to approach a true spring in character.

SPRINGS.

Springs are not only exceedingly numerous throughout large portions of the eastern United States, especially in the more rugged regions, but form a most important source of water supply. In many of the hilly districts they constitute, in fact, almost the only source of domestic supply. In general they are free from pollution and not too strongly mineralized for ordinary uses. Mineral springs, however, are not uncommon, and are much used for medicinal and table purposes, and have lead to the development of sanitariums and many large and popular pleasure resorts.

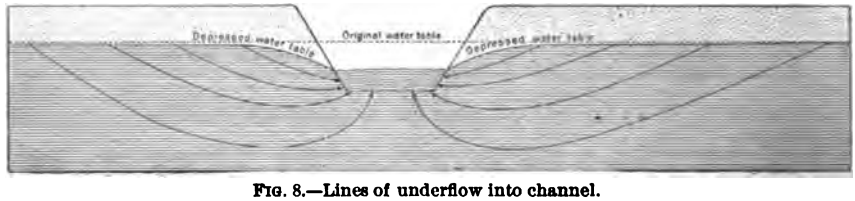


FIG. 8.—Lines of underflow into channel.

Seepage springs.—This term is applied when the water seeps out of sand or gravel, and differs from general seepage only in that it is restricted to a very small area. Such springs are usually marked by abundant vegetation at points of emergence, and the water as it collects is often colored or carries an oily scum due to the decomposition of vegetable matter. The scum is often mistaken for petroleum. Before using such a spring the vegetation should be cleared away and a small reservoir constructed, or tank sunk in the ground.

The waters of the seepage springs usually come from no great distance beneath the surface and are not usually very cold. Being fed by waters coming from near the surface they are sometimes likely to become polluted, and local conditions should be carefully studied before the water is used for drinking.

Seepage springs sometimes emerge along the top of an underlying impervious bed, but more frequently occur where valleys are cut downward into the zone of saturation of a more or less uniform water-bearing deposit, or where the water table comes to the surface near a stream, a lake, or the sea. Under favorable conditions the seepage from sands, as on Long Island, gathers into channels and forms streams of

A. SPRING FORMED AT OUTCROP OF AN IMPERVIOUS FLOOR.

B. ARTESIAN WELL.

considerable size, some of them flowing 5,000,000 gallons or more daily.

Springs from definite underground channels.—In this group is embraced a great variety of springs, including both those flowing in the small more or less tubular passages in the drift, and those occupying large solution channels or caverns in the soluble rocks.

The channels of the drift springs are generally established along some more or less sandy or other porous layer, or even in places along the path left by a decaying root. At first the motion appears to be mainly by seepage, but in many instances a passageway is gradually opened along which a definite stream finds its way. The waters reach the channels by percolation through the clays and sands, and are usually free from pollution. If such a channel, however, leads from a cesspool, or similar source of pollution, the water becomes highly charged with matter dangerous to the health. Once contaminated it is likely to continue so for long distances, as little natural filtration takes place, owing to the nature of the channel. The water should be thoroughly tested by a chemist if there seems any likelihood of contamination.

In limestones and other soluble rocks the underground passages are often many miles in length. Single passages, as in the Mammoth Cave of Kentucky, have been traversed for a distance of nearly 10 miles, while passages as yet undiscovered, but several times as long, probably exist. Some of these passages are many feet in diameter and are traversed by streams of considerable size, or even rivers. The Silver Springs of Florida give rise to a river which is navigable from the ocean to its source in the springs, while springs of similar volume occur elsewhere in Florida and Arkansas, and possibly elsewhere. The waters of such springs vary greatly in composition, although most of them are hard. Some waters are exceedingly clear, the bottoms of springs being distinctly visible at a depth of many feet, but in others the waters are muddy after severe storms. In the first case it is probable that the waters feeding the underground stream reached it by percolation through the porous earth or rock, during which its impurities were largely removed. In the second case the waters in part appear to have penetrated downward through sinks, or entered the rock directly as streams. In both cases they are very liable to pollution by impurities washed in with the water (see Pl. I).

Fissure springs.—The term fissure springs is here used rather comprehensively to include the springs issuing along bedding, joint, cleavage, or fault planes (Pl. IV, *A*). The distinguishing feature is a break in the rocks along which the waters can pass, it being immaterial whether any considerable open space exists. These springs differ from the preceding in that they are as a class of deeper-seated origin. Seepage and drift springs are largely confined to unconsolidated surface de-

posits, while the channels of limestone springs do not ordinarily extend much below the level of the surrounding surface drainage. In fissure springs, on the other hand, the waters are frequently derived from great depths, as is attested by their temperatures. The waters are almost never subjected to contamination, but are, however, often highly mineralized. Springs of this class are often scattered along

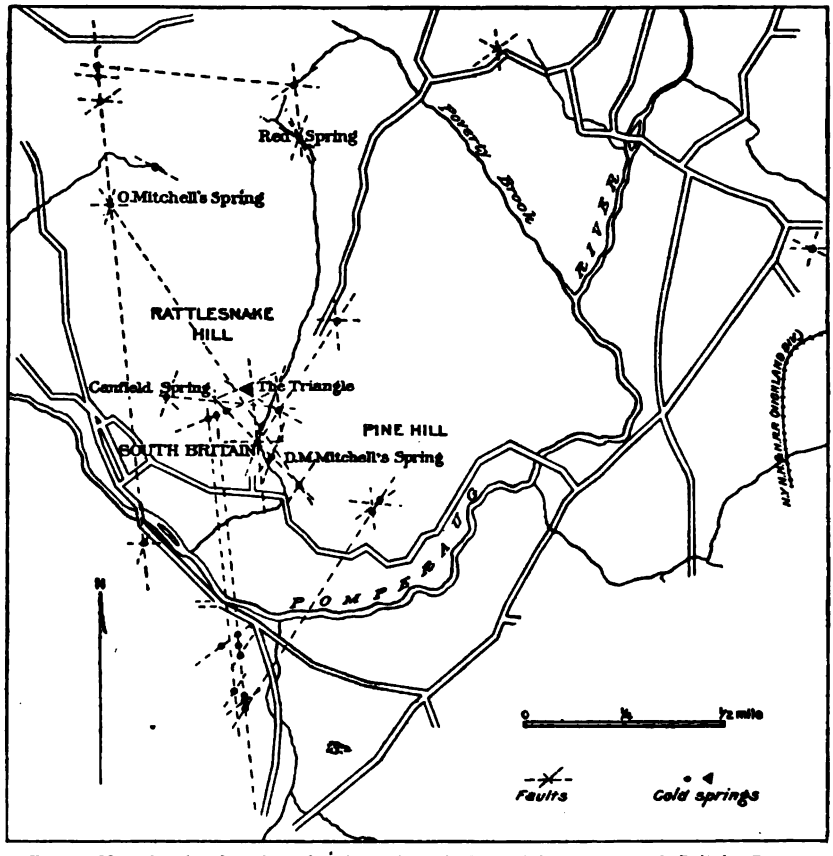


FIG. 9.—Map showing location of springs along faults or joints near South Britain, Conn. (After Hobbs.)

straight lines for considerable distances, their position being determined by lines of fracture or jointing, as shown in fig. 9.

Geysers.—Geysers are those springs in which at more or less regular intervals the water is ejected with some force. The waters are always warm or hot and, therefore, come from considerable depth. Geyser springs generally emerge from tubular conduits that are lined with silica, deposited by the water, and end at the surface in a cone of similar material. The ejection of the water is probably due to the expelling force of steam generated deep below the surface under certain peculiar conditions.

WELLS.

Wells are of three general classes: (1) Dug, (2) driven, and (3) drilled or bored. A few paragraphs will be devoted to their consideration, but detailed discussions will not be attempted.

Dug wells.—Dug wells are especially adapted to loose unconsolidated surface deposits in which the water supply is rather scanty. They present a large surface from which the water can enter and have a large storage capacity, but, on the other hand, they must necessarily be of limited depth, and because of the difficulty in keeping out surface and shallow-soil waters and other materials, are especially liable to pollution. They are also quite expensive and need to be frequently cleaned. They are undesirable if sufficient supplies can be had by driving or drilling.

Driven wells.—Driven wells consist of a pipe, with strainer and pointed end, which are driven into sand and similar soft deposits. They can be put down in a few hours, are exceedingly cheap, and effectively exclude surface waters. The principal difficulty arises from the penetration of sand and the clogging of the pipe. Driven wells furnish ideal supplies in many sandy regions, but are, of course, not adapted to the conditions existing over the greater part of the country.

Drilled and bored wells.—These include those wells drilled by machinery in rock or other deposits. Many different methods of drilling are employed, the one used at a particular point depending upon the material to be encountered or upon the nature of the well demanded. Among the most common are: (1) The ordinary churn-drill method, in which the drill is rapidly lifted and dropped, forcing its way down by impact; (2) the diamond-drill method, in which a cylinder set at the bottom with diamonds is rotated, cutting out a core of the rock; (3) the steel-shot method, in which loose chilled steel shot takes the place of diamonds, and (4) the jet process, in which a current of water is forced from the lower end of the pipe and by loosening the surrounding material allows the latter to sink. Many other methods or modifications are in use. Pl. IV, *B*, represents one of the deep drilled wells yielding flowing water.

PUMPS.

In raising water to the surface a variety of methods are used, but except for the bucket of the open wells they all depend upon some type of pump. Of the hand pumps, the ordinary valve pump, the chain pump, and the force pump are the most common. For raising large supplies windmills usually afford a cheap and satisfactory method on the farm, but in industrial establishments, where not only a large

but a constant and steady supply is needed, some form of power pump is used. Electricity, steam, and gasoline are all used, the latter being especially popular because of cheapness and ease of operation. Various forms of "air-lift" processes, by which water is lifted by a current of air that is forced into the well tubing, are successfully used.

ARTESIAN FLOWS.

ESSENTIAL CONDITIONS.

Stratified beds.—In 1885 Prof. Thomas C. Chamberlin, in a paper entitled "Requisite and Qualifying Conditions of Artesian Wells,"[a] explained the principles of artesian flow, and called attention to many of the special conditions which tend to determine the success or failure of these wells. The conditions which, according to Professor Chamberlin, may properly be considered as those of true artesian flow are as follows:

I. A pervious stratum to permit the entrance and the passage of water.
II. A water-tight bed below to prevent the escape of water downward.
III. A like impervious bed above to prevent the escape upward, for the water, being under pressure from the fountain head, would otherwise find relief in that direction.
IV. An inclination of these beds, so that the edge at which the waters enter will be higher than the surface at the well.
V. A suitable exposure of the edge of the porous stratum, so that it may take in a sufficient supply of water.
VI. An adequate rainfall to furnish this supply.
VII. An absence of any escape for the water at a lower level than the surface at the well.

Some of the features outlined above are illustrated by the following diagrams taken from Professor Chamberlin's report. There are many

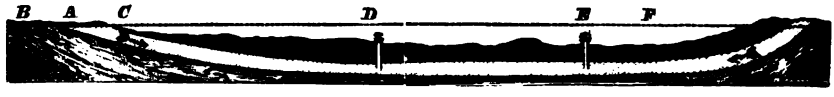


FIG. 10.—Section showing principal requisites of artesian wells. *A*, a porous stratum; *B*, *C*, impervious beds below and above *A*, acting as confining strata; *F*, height of water level in porous beds *A*, or, in other words, height of reservoir or fountain head; *D*, *E*, flowing wells springing from the porous water-filled bed *A*.

other minor conditions and modifications of the requisites outlined above which bear on the occurrence of artesian waters, but the essentials are here given.

Joints and faults.—Flowing water is not confined to those wells which penetrate beds under the conditions outlined by Professor Chamberlin. The principle on which artesian waters depend is equally applicable to other rocks, the essential feature being simply that the water be confined and that the outlet through the well be considerably

[a] Fifth Annual Rept. U. S. Geol. Survey, pp. 125-173.

lower than the catchment area at which the water entered. A bedding, joint, or fault plane, or other fissure in insoluble rocks, or a solution passage in limestones, sometimes affords favorable conditions for artesian flows, although because of their commonly limited development

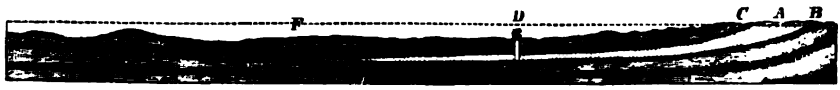


FIG. 11.—Section illustrating thinning out of porous water-bearing bed *A*, inclosed between impervious beds *B*, *C*, thus furnishing conditions for artesian well *D*.

they are far less frequently encountered than the broad porous sandstones and other sedimentary beds.

Besides occurring along bedding planes or along joint or fault planes water frequently follows a combination of passages, such as indicated in fig. 13, which shows an inclined bed cut by a joint, the motion of

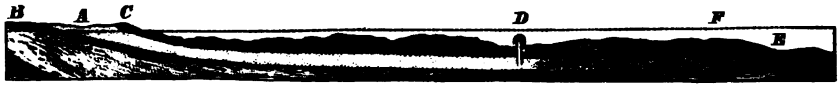


FIG. 12.—Section showing transition from porous to impervious bed. *A*, a close-textured, impervious bed, inclosed between impervious beds *B* and *C*, furnishes conditions for an artesian well *D*.

the water being indicated by the arrow. Exactly the same conditions might occur if the bed *b* were to be replaced by a joint or fault plane of the same position.

Direction of movement of water.—In the majority of cases the water encountered by wells is moving down the dip of the beds or down the

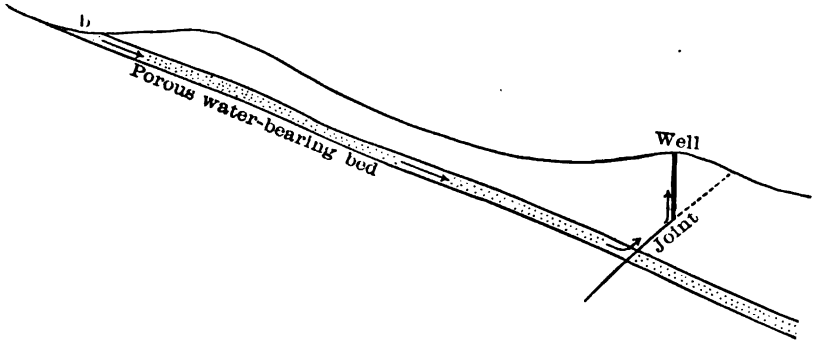


FIG. 13.—Upward circulation of water along joint.

joint or fault line, but in many instances, as in the cases outlined above and illustrated in fig. 13, the water may be moving upward.

UNDERGROUND WATER CONDITIONS IN EASTERN UNITED STATES.

There are great differences in the underground water conditions in different parts of eastern United States. These are due in part to the presence in the northern half of a mantle of surface deposits left by glaciers or by streams connected with the ice. A part of the

difference is also due to the difference in weathering of the rocks in the northern and southern portions, while still another part is due to variations in the character of rocks and of topography.

AREA OF GLACIAL DRIFT.

This area is bounded on the south by a line which, starting at Nantucket, passes through Marthas Vineyard, Long Island, across New

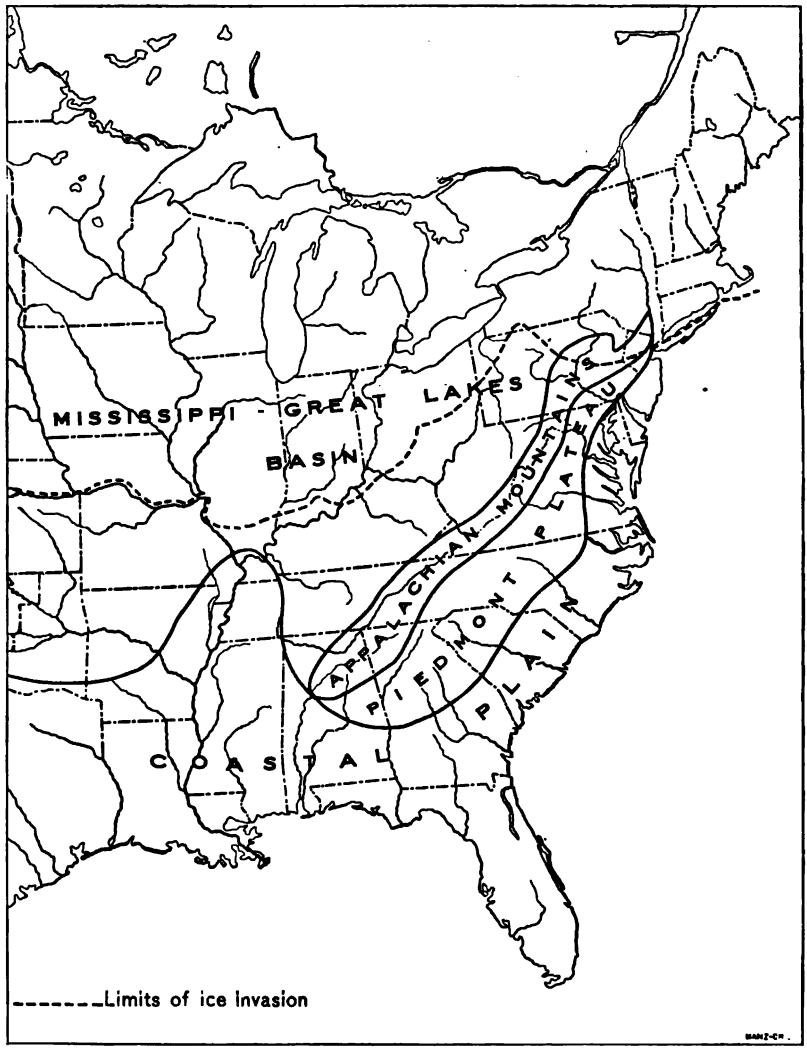


FIG. 14.—Geologic and water-supply districts in eastern United States.

Jersey, northwestward across Pennsylvania into New York, then southwestward across Pennsylvania and Ohio to the vicinity of Cincinnati, where it crosses the river for a short distance into Kentucky,

thence westward across southern Indiana, Illinois, and central Missouri, to a point near Kansas City, where it leaves the region under consideration (see fig. 14). All of the region north of this line was covered one or more times by great ice sheets, except a small area in southwestern Wisconsin and adjacent portions of Minnesota, Iowa, and Illinois, where there appears to have been a sort of island of land surrounded by ice, known as the "Driftless area."

North of the boundary mentioned the surface, except for the small driftless area, is covered with a mantle of materials deposited by the glacier and known as drift. The drift is divided into two main types, the first known as till, and the second as modified or stratified drift. Till is composed of a heterogeneous mass, consisting of clay, sand, and bowlders, frequently known as hardpan. It was deposited mainly directly by the ice, either beneath the sheet or at its margin. The second class of drift includes gravels, sands, and other stratified deposits formed by streams leading outward from the ice sheet. It is found chiefly along the valleys which were once occupied by glacial streams, but considerable amounts were also deposited in temporary glacial lakes which existed between the northward sloping land and the retreating ice sheet, while some was laid down as broad wash plains.

The glaciers which left the various types of drift started in the far north in relatively recent geologic times and spread southward to the limits mentioned. Before their advance the rocks were probably deeply weathered and covered with soil, as in the South at the present time, although the extent of the weathering was doubtless somewhat less. The first work of the ice was to remove this soft weathered material. Part was incorporated with the till and part was carried off by the streams to form clay and sand deposits. Later, after the removal of the surface soil, the glacier began the work of wearing down the solid rocks, plucking off fragments both large and small from the ledges and transporting them southward. This material was also left in part in the till, and in part carried away by the streams.

The effect of the drift on the water supply of the northern portion of the country is very great. In general the drift holds very much more water than any of the rocks. This water is yielded readily to shallow wells, and furnishes by far the larger part of the well supplies in the region where it occurs. Water is least abundant in the till and most abundant in the stratified drift. Its occurence in till and in sand and gravel has already been described (see pp. 25–26).

WEATHERED ROCKS.

South of the limits of glacial advance the place of the drift is partly taken by the weathered or decomposed rocks. The weathering seems to be deepest in the south where the climate is more humid and, therefore, more favorable to rock decay.

The soils south of the drift limits consist of small fragments or particles of disintegrated rocks. They are usually colored red and yellow by weathering and are very porous, absorbing much water. Their thickness, however, is not sufficient to make them a good source of water supply, although they yield water to many shallow wells. The water is subjected, as in sands and similar materials, to more or less complete filtration in its passage downward.

ROCK WATER PROVINCES.

Leaving out of account New England and eastern New York, which compare most nearly with the Piedmont Plain, the main divisions of the eastern United States, viewed from the standpoint of underground water supplies, are: (1) The Coastal Plain, (2) the Piedmont Plateau, (3) the Appalachian Mountains, and (4) the Mississippi and Great Lakes basin. The limits of these divisions are shown in fig. 14.

Coastal Plain.—The Coastal Plain consists of a strip of unconsolidated deposits, extending from Long Island on the north along the Atlantic and Gulf States into Mexico on the south. The width varies from a few miles at the north to several hundred miles in the Mississippi River region.

The surface of the Coastal Plain is low, usually not exceeding 100 to 300 feet above sea level and, where uncut by erosion, is generally flat. Owing to the soft character of the materials, however, the streams have generally cut fairly deep valleys which are separated, where not too close together, by flat-topped ridges marking the original surface. Where the streams are close together the surface is cut into rolling hills.

The materials include clays, sands, gravels, marls, and a few more or less solid limestones, the latter being present mainly in the Southern States. A few of the sandy layers have been consolidated and now form sandstones. The beds dip gently toward the coast. The waters in the North occur mainly in sands and gravels, especially in those at the base of the Coastal Plain deposits. Farther south, particularly in the Gulf States, water is found both in sands and in the porous limestones. The quality of the water in the gravels in the northern portion of the belt is generally soft and good, but farther south, notably where sands and gravels alternate with clay or limestone beds, the waters are often hard or are charged with sulphur and iron. The capacity of the wells is generally large and many of them flow without pumping. In the aggregate there are several thousand deep wells scattered throughout the Coastal Plain. They are used principally for domestic and farm supplies, but some of them that yield soft waters are utilized for industrial purposes. In the Gulf States, especially in Louisiana, a large number of wells furnish water for the irrigation of

ice. A considerable number are also used as a source of public water upplies.

Piedmont Plateau.—The Piedmont Plateau proper consists of a elt of crystalline rocks, including a few small basins of Triassic ediments, that extends southward from southeastern New York long the east front of the Appalachian Mountains to Alabama, lying etween the mountains and the Coastal Plain. Where the plateau oins the Coastal Plain its elevation is only a few hundred feet, but he altitude of its surface increases gradually toward the northwest, ntil at the base of the mountains, especially in western North Carona and vicinity, its highest points have an altitude of several thouand feet. In the main its surface, where uncut by streams, is flat or gently rolling, but in its higher portions it has been cut into a series of prominent mountains. In the vicinity of the streams near the coast it is also cut into a series of lower hills, as in the case of the Coastal Plain.

The rocks of the Piedmont Plateau proper consist mainly of schists, gneisses, granites, and other metamorphic or igneous rocks, all of which are of crystalline texture. The rocks of the Triassic basins consist mainly of sandstones, shales, etc.

The waters of the Piedmont Plateau are relatively uncertain in occurrence, depending largely on the existence of joints or other fissures in the rocks, but good supplies have nevertheless been obtained at numerous points. In composition the waters are usually fairly good, although they sometimes contain considerable mineral matter. Relatively few deep wells have been sunk in this region, owing to the uncertainty of supply, dependence being placed largely on streams or on shallow wells dug in the weathered upper portion of the rocks. The waters are used largely for domestic and farm purposes and in small industrial establishments. In a few places public water supplies are obtained from the Piedmont rocks, and some important mineral springs are found in the region.

Similar to the Piedmont Plateau are the great areas of igneous rocks in Minnesota and Wisconsin and in New York and New England. The topography of the rocks in these regions is in general somewhat more rugged than in the Piedmont Plateau proper, and less use is made of the waters, largely because of the abundance of lakes, springs, and spring-fed streams, or of waters in the glacial drift which overlies the crystalline rocks in this portion of the country.

Appalachian Mountains.—The Appalachian Mountains may be considered as beginning in eastern Pennsylvania and extending southward to central Alabama. The Berkshire Hills in Connecticut and Massachusetts and the Green Mountains in Vermont are included in the area by some. The rocks throughout the region are strongly folded and broken by faults, the harder beds giving rise to the great mountain ridges

which characterize the belt. The rocks consist of quartzites, sandstones, shales, and limestones. The sandstones and certain of the limestones carry considerable amounts of water, but are seldom used as a source of supply. The water in the limestones is carried in definite channels and is of rather uncertain occurrence. Both the sandstones and limestones yield copious springs in places. Wells in the synclines or rock troughs frequently yield water which will sometimes rise to the surface, but in general dependence is placed on the springs which occur in large numbers throughout the belt. In the wider limestone valleys wells or cisterns are often used. There are very few cities or large industrial establishments in this region and deep wells are therefore somewhat rare.

The Mississippi-Great Lakes basin.—This basin includes the remaining portion of the territory in the eastern half of the United States. The surface is moderately low, seldom exceeding 1,000 feet in elevation, and is usually not characterized by prominent hills or mountains. Except in the areas of igneous rocks, noted above, the rocks consist of flat or very gently folded sandstones, limestones, shales, etc., varying from Cambrian to Carboniferous in age. The Cambrian and other of the older sandstones carry large amounts of water, which is obtained by wells that frequently flow at the surface. The Silurian limestones also contain considerable water, but, as is the case with water in limestones elsewhere, its occurrence at a particular point can seldom be predicted.

The younger rocks, including the Devonian and Carboniferous, consist to a considerable extent of alternations of shales, shaly limestones, and sandstones. In the limestones the water occurs very much as in other limestones. In the sandstones and shales, however, its occurrence is uncertain owing to the lack of persistence of the beds. One well may obtain water, while another a few feet away may fail. The waters are often mineralized, especially in Michigan, where they contain a high percentage of salt. The Carboniferous limestones abound in springs, some of which are of great size.

MAINE.

By W. S. Bayley.

TOPOGRAPHY AND GEOLOGY.

The surface of Maine consists essentially of an extensive southward-facing slope draining directly into the Atlantic Ocean and a smaller northward-facing slope draining into St. John River. The latter area is a great plain covered largely by swamps and interrupted by a few irregular-shaped hills. The surface of the southern slope is much more broken. It is crossed by many ridges of low mountains trending east or northeast, some of which rise several thousand feet above the platform on which they rest. These are separated by wide areas of plain, on which are many small glacial hills and ridges. Near the coast the surface is rough. Rocky ridges and low, bare hills stretch from the shore line some miles inland, but the hills are not lofty and the valleys between them are not deep.

All the rocks are Paleozoic or older, except the very late marine clays and the glacial deposits. The northern portion of the State is underlain by moderately folded Silurian and Devonian limestones, shales, and sandstones, cut here and there by igneous rocks, some of which are certainly volcanic. In this area the conditions are the most favorable for the occurrence of artesian waters.

The section bordering the coast is underlain by granites, gneisses, crystalline schists, and ancient lavas intersected by intrusives. The central portion of the State, between the northern and the coast belts, is composed of slates, quartzites, and impure limestones, very much like the rocks in the northern belt, but usually more crystalline and more closely folded. These, too, are cut by granites and other intrusives. Conditions are not so favorable for artesian water in the central and the coast belts as they are in the northern belt; nevertheless, in some areas within them, where the rocks are less highly tilted than elsewhere, or where they are much fissured, artesian waters have been developed. Springs, moreover, abound and a few drilled wells deliver water at the surface.

Upon the rocks of all three belts the glaciers that once covered the entire State deposited clay, sand, gravel, and a mixture of clay and bowlders. The latter constitutes the till, which covers all the older rocks as a blanket, varying in thickness from a few inches to many feet. The clay, sand, and gravel form terraces, hills, and ridges that run in gently sinuous lines for long distances over hill and valley, following, in the main, the directions of the principal drainage lines. In these deposits the various components are often interstratified, furnishing ideal conditions for successful shallow wells. Most of these wells obtain water either from the sand and gravel layers interleaved between the clay beds or from the rock surface underlying all the sediments.

The only remaining rocks that are at all widely spread in Maine are the beds of fossiliferous marine clays, which extend far inland up the river valleys and into lowlands where the elevation is not more than 230 feet above sea level. Over these clays are layers of river sand, deposited at a time when the streams were being fed by the melting glaciers. At the base of this sand, where it lies upon the clay, there is usually a constant sheet of water moving slowly riverward. This furnishes an unfailing source of supply to wells situated near the river banks, but unfortunately the water is often contaminated with impurities of various kinds.

WATER SUPPLY.

With the exception of Florida, Maine is the least densely populated of all the Eastern States. Because of this low density (23.2 per square mile) and its abundance of lakes and streams, its people have felt little necessity for seeking sources of water supply below the surface. Consequently, the underground waters of the State have been, on the whole, but slightly utilized, except in certain restricted areas, where, for one reason or another, the surface waters are not suitable for domestic or manufacturing purposes.

Until very recently the rivers and lakes have afforded excellent water for nearly all purposes. With the increase in the number of factories established on the main waterways for the advantages resulting from the possession of cheap water power, the rivers have become less and less valuable as sources of water supply, partly because of the waste products poured into them from the factories and partly because of the increased amount of sewage which they must carry in consequence of the growth of the manufacturing communities on their banks.

The drift of the population toward centers is well shown by the census of 1900. The number of cities and villages separately enumerated in this year was 43, as against 25 in 1890, and their population was 258,431, as against 184,821, or 37.2 per cent of the total population in 1900, as against 28 per cent in 1890.

The natural result of the two tendencies above mentioned has been to pollute the principal water courses, with the consequent result that communities drawing their public supplies from streams are beginning to complain of the quality of the water furnished them and are turning toward the lakes for relief.

Along the coast strip, where the larger rivers are tidal, communities are dependent upon lakes and small brooks for their public supply. On the islands the principal sources of drinkable water are springs and drilled wells, but since there are only a few island settlements of any considerable size the question of large public supplies is not of great moment.

Within the interior of the State village communities that are not situated near large lakes or spring-fed brooks have often taken advantage of the numerous good springs that abound everywhere and spring water has been piped through the settlements.

PUBLIC SUPPLIES.

The aggregate population furnished by water corporations from the three principal sources above mentioned is about 285,000, or about 40 per cent of the entire population of the State. Of this number about 152,000 obtain public water from lakes, 122,000 from rivers, and 14,000 from springs. In addition there is one community (Castine, population about 900) that draws its supply from four drilled wells.

RIVERS.

The communities at present obtaining their public supply from rivers and brooks are as follows:

Preliminary list of communities drawing upon streams as the sources of their public water supply.

Place.	County.	Source of supply.
Augusta	Kennebec	Kennebec River.
Bangor	Penobscot	Penobscot River.
Belfast	Waldo	Little River or Coles Brook.
Bethel	Oxford	Chapman Brook.
Benton	Kennebec	Messalonskee River.
Biddeford	York	Saco River.
Brewer	Penobscot	Penobscot River.
Calais	Washington	St. Croix River.
Caribou	Aroostook	Aroostook River.
Dover	Piscataquis	Piscataquis River.
Ellsworth	Hancock	Branch Pond Stream.
Ellsworth Falls	do	Do.
Fairfield	Somerset	Messalonskee River.
Freeport	Cumberland	Brook.
Fryeburg	Oxford	White Lot Brook.
Gardiner	Kennebec	Cobossecontee Stream.
Oldtown	Penobscot	Penobscot River.
Houlton	Aroostook	Moose Brook.
Kingfield	Franklin	Brook flowing into Tuffs Pond.
Milltown	Washington	St. Croix River.
Old Orchard	York	Saco River.
Pittsfield	Somerset	Sebasticook River.
Presque Isle	Aroostook	Kennedy Brook.
Richmond	Sagadahoc	Kennebec River.
Rumford Falls	Oxford	Androscoggin River.
Saco	York	Saco River.
Somerville	Lincoln	Sheepscot River.
Sorrento	Hancock	Piscataquis River.
South Berwick	York	Two Brooks.
Van Buren	Aroostook	St. John River and Violette Brook.
Waterville	Kennebec	Messalonskee River.

LAKES.

The list below is an enumeration of the communities utilizing lakes as their sources of supply.

Preliminary list of communities utilizing lakes as sources of water supply.

Place.	County.	Source of supply.
Auburn	Androscoggin	Lake Auburn or Wilton Pond.
Bar Harbor	Hancock	Eagle Lake.
Bath	Sagadahoc	Lake Nequassetto.
Bath (emergency)	do	120 driven wells.
Belgrade	Kennebec	Belgrade Lake.
Boothbay Harbor	Lincoln	Adams Pond.
Brunswick	Cumberland	
Camden	Knox	Mirror or Oyster River Lake.
Gorham	Cumberland	Sebago Lake.
Kittery	York	Folly Pond.
Lewiston	Androscoggin	Lake Auburn.
Livermore Falls	do	
Newport	Penobscot	Pillsbury Pond.
Norway	Oxford	Norway or Great Pennesseewassee Lake.
Oakland	Kennebec	Messalonskee Lake.
Phillips	Franklin	Mount Blue Pond.
Portland	Cumberland	Sebago Lake.
Rockland	Knox	Mirror or Oyster River Lake.
Rockland (auxiliary)	do	Lake Chicawanstin.
Rockport	do	Mirror or Oyster River Lake.
Seal Harbor	Hancock	Jordan's Pond.
South Portland	Cumberland	Sebago Lake.
South Paris	Oxford	Norway Lake.
Southwest Harbor	Hancock	Long Pond.
Thomaston	Knox	Mirror or Oyster River Lake.
Westbrook	Cumberland	Sebago Lake.
Wilton	Franklin	
Woolwich	Sagadahoc	Lake Nequassetto.
York	York	Chase's Lake.
York Corner	do	Do.

SPRINGS.

In the communities named below springs furnish nearly all the water used. In all cases this is carried by pipes either directly from the springs or from reservoirs into which the spring water is pumped.

Preliminary list of communities obtaining their public supply from springs.

Place.	County.	Remarks.
Addison	Washington	
Appleton	Knox	
Bingham	Somerset	2 springs fill 1½-inch and 6-inch pipes.
Brownville	Piscataquis	3 springs; piped to hotel and private houses.
Cherryfield	Washington	
Fort Fairfield	Aroostook	
Guilford	Piscataquis	Supplies 30 families.
Hallowell	Kennebec	
Harrington	Washington	
Lisbon Falls	Androscoggin	
Lubec	Washington	350,000 gallons a day. Temperature, 42°.
Millbridge	do	Fills 2-inch pipe. Temperature, 40°.
Monson	Piscataquis	Supplies 30 families.
North Waterboro	York	
Paris Hill	Oxford	From 10,000 to 30,000 gallons a day.
Peru	do	
Sanford	York	Fills ⅛-inch and ¾-inch pipes.
Sangerville	Piscataquis	
Searsmont	Waldo	
Searsport	do	
Skowhegan	Somerset	500,000 gallons a day.
Springvale	York	100 gallons a minute.
Stratton	Franklin	
Union	Knox	
Winterport	Waldo	125,000 gallons a day.
Yarmouth	Cumberland	120,000 gallons a day. Temperature, 49°.
Yarmouthville	do	

DRILLED WELLS.

The village of Castine is furnished with water for domestic and fire purposes by four drilled wells, of which three, situated at an elevation of 130 feet, are now used. In these the water was struck at a depth of 62½ feet, or 67½ feet above mean high-water mark. It rises naturally within 25 feet of the surface and is pumped to the surface with the aid of a windmill. These wells yield 40,000 gallons daily.

A fourth well, 675 feet deep, is located at an elevation of 217 feet. Water was struck in this well at a depth of 620 feet. It apparently came from fissures in the rock. The water level in this well is only 27 feet below the surface—i. e., it is 127½ feet higher than the level in the lower wells and 190 feet above sea level. All the wells are situated on the backbone of a small peninsula that extends into Penobscot Bay. This peninsula is only 2 miles long and 1 mile wide, and is joined to the mainland by a narrow isthmus which has been crossed by a canal. The deepest well, whose water rises 190 feet above sea level, is only half a mile from the shore of the bay.

PRIVATE SUPPLIES.

The farming communities in Maine, as elsewhere in the Eastern States, consist of isolated families or very small groups of families in villages that are not large enough to warrant the wholesale distribution of water. Water can not be conveyed to them economically from long distances, hence their supplies must come from near-by sources, which are available almost everywhere immediately beneath the surface. These underground sources are tapped by dug and by drilled wells, or by the natural fissures through which springs issue.

DUG, DRIVEN, AND BORED WELLS.

The soil covering of Maine is largely glacial in origin. The drift which covers the hard rocks is of considerable thickness over most of the State, and from its nature it affords many reservoirs for the storage of ground water. Where gravels and sands are intercalated between clay beds these furnish abundant water. The depth of the layers from which the water is derived varies widely even in the same neighborhood, because the coarse-grained beds are not of great horizontal extent, and neighboring wells, therefore, must often obtain their water from different layers. In those places where the drift covering is thin the rock under the drift is blasted into, and in this way a shallow basin is made, into which water seeps from the basal layers of the overlying drift and from the crevices opened up in the rock.

In the valleys of many of the rivers are deposits of clay, which were either laid down by the rivers themselves or by bays of the ocean which formerly extended inland up the river valleys. Between the successive beds of clay are often thin layers of water that are continuously flowing riverward as broad sheets. Where these are intercepted by wells an abundant and constant supply of water is obtained. Wells of this class possess, in a measure, artesian characters. The water often rises above its immediate source, and its height is only slightly affected by droughts. On the other hand, the beneficial effect of sand filtration upon the water is lacking, and consequently these wells are more apt to become polluted than those that obtain their

water by tapping supplies in sand or gravel. A rapid examination of the records of the State board of health shows that the greater proportion of the polluted wells investigated by the board are those which obtain their water from between clay layers; whereas, on the other hand, the wells obtaining their supply from the sand beds in the drift usually furnish good water, although they may be situated in the midst of farm buildings that have occupied the land for periods of fifty or seventy-five years.

DRILLED WELLS.

Because of the abundance of streams, lakes, and springs in the State, and the ease with which the underground water in the glacial drift may be reached by dug, driven, and bored wells, the use of drilled wells is not common. There are a few in the interior counties where the supply of surface water is not constant and where the drift is thin and dug wells are likely to fluctuate with variations in the amount of rainfall, but by far the greater portion of the deep wells are situated either on the islands off the cost or in a narrow strip on the mainland bordering the shore. This shore strip is almost insular in character. Deep inlets extend back into the land, separating it into narrow tongues that are almost surrounded by salt water. Moreover, the drift covering is usually thin, and in this belt, as on the islands, the collecting areas are small and the capacity of the drift for storage is small.

Records of the rocks drilled through have been kept for very few of the wells. This fact, together with the fact that the geology of the State is practically unknown, makes it impracticable to work out at present the limits of artesian basins. From the scanty data at hand, however, it appears probable that at least one basin exists in the northeastern part of the State, in the eastern portion of Aroostook County, and another in the west-central part, surrounding Moosehead Lake.

At Greenville, at the mouth of Moosehead Lake, are two wells that flow. These two and a few others in the coast belt are the only ones that furnish water at the surface. In the great majority of the wells, however, the water is forced upward by natural pressure some distance above its source.

Of the 448 drilled wells of which reports have been received, 134 are 100 feet deep or over. Of these there are 2 over 500 feet deep, 7 between 300 and 400 feet, and 25 between 200 and 300 feet.

SPRINGS.

Throughout the interior of the State springs are frequently used as sources of water supply when they are situated at a greater elevation than the buildings to be furnished with water. Often several families combine and have the water of the larger springs distributed through their dwellings by pipes. Occasionally the water is raised by wind-

mills, but usually it is distributed by gravity alone. In those portions of the State where the well water is hard, springs are more generally utilized than in those portions where the well water is soft. In a few instances where the quality of the water in the streams near by is poor, springs supply water for manufacturing establishments.

Very important springs, which are of great economic value to the

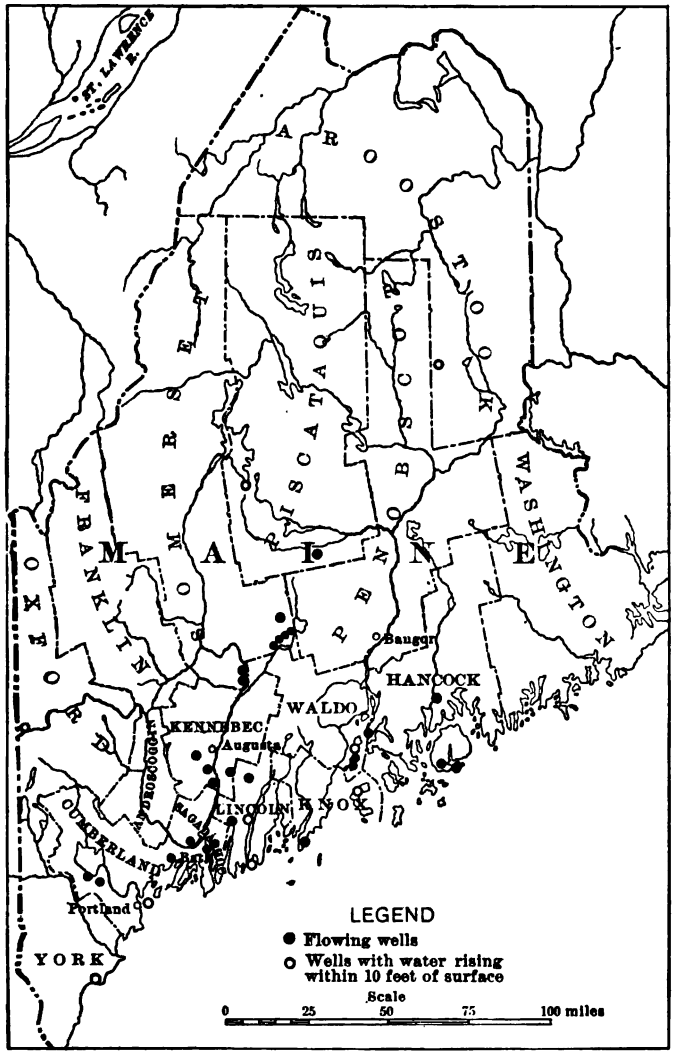


FIG. 15.—Location of flowing or nearly flowing wells of Maine.

State, are those which may be denominated commercial springs. This group includes those springs whose waters are sold by measure, i. e., in small parcels. Of this class there are two subclasses. In the first are included springs that furnish water to consumers in their vicinity

at regular intervals, to be used as table water. In this group there are at present known to be 25 springs, from which 486,000 gallons are sold at a cost to the consumers of $29,782. A list of these, with analyses of their waters, is given in the table on pages 51 to 53. The second subclass includes springs whose waters are bottled and shipped to distant points. The mineral springs whose waters are supposed to possess medicinal properties are included here, and also certain other springs whose water is exceptionally pure. The quantity of water shipped from these in 1902 was 355,865 gallons, valued at $71,415. This amount does not include the sales of water from Poland Spring, the proprietors of which decline to make any statement as to the quantity or value of the water supplied by them to consumers. It is known, however, that the aggregate value of the water shipped from this spring is greater than that of all the other springs in the State. The springs in this group number 22. (See table on page 54.)

Preliminary list of springs furnishing water sold in their vicinity.

Name.	Location.	County.	Flow per minute, in gallons.	Temperature.	Remarks.
				°F.	
1. Rocky Hill	1¼ miles north of Fairfield	Somerset	3		Sold in Waterville and Fairfield.
2. Arctic	1½ miles north of Bangor	Penobscot	8	44	Sold in Bangor. Hardness, 6 per 100,000.
3. Puritan	3 miles west of Pine Point	York	2½	47	Sold in York and vicinity.
4. Granite	Long Island, Casco Bay	Cumberland		40	Piped into hotel.
5. Seavey's Purity	1 mile southwest of West Scarboro	do	3	40	Hardness, 2,128 per 100,000.
6. Forest	6 miles west of Gardiner	Kennebec	2	42	Sold in Gardiner and neighboring towns.
7. Do	do	do	2	42	
8. Do	do	do	2	42	
9. Paradise	1¼ miles east of Brunswick	Cumberland	8	43–45	Sold in Brunswick.
10. Cliff	¼ mile west of East Turner	Androscoggin	1½	Warm.	Sold in Lewiston.
11. Ticonic Mineral	2 miles northeast of Waterville	Kennebec	5½		Sold in Waterville. Hardness, 15.5 per 100,000. Sulphureted.
12. Seal Rock	1 mile east of Saco	York	9½	Cold.	Sold in Biddeford and Saco.
13. Mount Desert	1 mile north of Northeast Harbor	Hancock	12	42	Sold in vicinity.
14. Littlefield's	½ mile west of Gardiner	Kennebec			Sold in Gardiner and vicinity.
15. Morse's	6 miles southwest of Gardiner	do			Do.
16. Pine Grove	5 miles southeast of Pittsfield	Waldo	60–100	48	Sold in Pittsfield and vicinity.
17. Chapman's	¼ mile north of East Orrington	Penobscot	Large.	Cold.	Sold in Brewer.
18. Lowrie's	2 miles northeast of Eastbrook	Hancock	10	40	Used in hotel.

Preliminary list of springs furnishing water sold in their vicinity—Continued.

Name.	Location.	County.	Flow per minute, in gallons.	Temperature.	Remarks.
				°F.	
19. Jones's	½ mile west of Norway	Oxford	½	Very cold.	Sold in Norway.
20. Pure Water	1½ miles north of Waterville	Kennebec			Sold in Waterville. Hardness, 4.15 per 100,000. Carbonated.
21. Vienna Sparkling	¼ mile from Vienna	do	2		
22. Skid Hill	¾ mile east of Poland	Androscoggin	30		Used in hotel.
23. Keystone Mineral	East Poland	do	5		
24. Hallowell	⅛ mile southwest of Togus	Kennebec			Supplies Soldiers' Home.
25. Sylvan	Durham	Androscoggin	1	40	

Analyses of water of springs listed above.

[Parts per million.]

	$CaCO_3$	$MgCO_3$	$FeCO_3$	Na_2CO_3	$CaSO_4$	$MgSO_4$	Na_2SO_4	K_2SO_4	NaCl	Fe_2O_3	Al_2O_3	SiO_2	Org.	Total.	Analyst.
1[a]	24.1	12.7		1.5	3.4			0.9	4.0			11.0	5.4	63.0	F. C. Robinson.
6	55.4	5.6		[b]2.4			8.0	6.2	4.8	trace.		14.2	3.0	99.6	Do.
7	21.6	5.3		[b]4.0			1.3	1.7	4.5			13.7	3.3	55.4	Do.
8	5.4	1.6		3.0			.5	1.3	3.5			9.5	3.0	27.8	Do.
9	1.7	1.0	0.2	4.2		1.0			[c]2.6			6.6	.3	17.7	Do.
10	6.7	4.8				4.4			6.3	1.9		5.6		29.7	L. G. Jordan.
11[d]										trace.		10.6		184.7	S. K. Hitchings.

18	4.0	1.7	.....	.....	.....	.....	2.6	.....	4.4	.2	7.3	.....	20.3	J. W. Baird.
21 [a]	32.0	5.4	.....	trace.	.....	.....	.....	4.3	.3	.9	8.2	.00	51.2	C. F. Chandler.
21 [b]	10.6	3.3	.....	12.2	.....	.....	.....	1.0	.2	trace.	15.1	.00	42.4	S. D. Hayes.
23	.....	11.1	7.7	5.1	.....	.....	4.3		4.3	4.3	14.5	trace.	.....	R. C. Stanley.
24	10.0	2.9	.....	.....	.....	.....	2.8	.....	[e]12.0	.....	15.0	6.3	49.5	Unknown.
25	3.8	2.4	.....	.....	.....	3.6	.....	2.0	9.8	2.2	5.1	.....	28.9	L. G. Jordan.

[a] The figures to the left correspond to those preceding the names of the springs in list of springs.
[b] Traces Li_2CO_3.
[c] Including KCl.
[d] Other compounds determined in this water, in parts per million, are CaO, 59.5; MgO, 16.4; FeO, 7.4; Na_2O, 26; K_2O, 6; Cl, 5.6; CO_2., 51; SO_4, 2.2; P_2O_5, trace.
[e] Including KCl, 0.6.

Preliminary list of springs furnishing water that is shipped.

Name.	Location.	County.	Flow per minute (in gallons).	Temperature.	Remarks.
				° F.	
1. Mount Oxford	2 miles north of Buckfield	Oxford	4	40	
2. Carrabassett	9 miles north of Kingfield	Franklin	10	42	
3. Ishka	1 mile south of West Hancock	Hancock	4	Cool.	Hardness, 41.5 per 1,000,000.
4. Pine	2½ miles southeast of Topsham	Sagadahoc	5	45	
5. Auburn Diamond	1 mile northwest of Auburn	Androscoggin	15	41	
6. Glenwood	2 miles north of St. Albans	Somerset	60	48	
7. Pownal	1½ miles north of West Pownal	Cumberland		42	
8. Bluehill	2½ miles northwest of Bluehill	Hancock	6	45	Hard, alkaline, chalybeate.
9. Bluehill	do	do	5	55	Soft.
10. Mount Hartford Cold	4 miles north of Buckfield	Oxford	3½	38	Lithia.
11. Hill's Mineral	1 mile east of Saco	York	1	42	
12. Zircon Moon Tide	Zircon	Oxford	14	40	
13. Underwood	6¾ miles northeast of Portland	Cumberland	140	46	
14. Boothbay Medicinal	East Boothbay	Lincoln	2½		Chalybeate; carbonated.
15. Windsor Mineral	2½ miles northeast of Lewiston	Androscoggin	10	48	Chalybeate.
16. Auburn	5 miles north of Auburn	do	25	49	
17. Addison Mineral	1½ miles east of Addison	Washington	30	35	Chalybeate; carbonated.
18. Samoset Mineral	½ mile west of Nobleboro	Lincoln	½	Cold.	Carbonated; sulphureted.
19. Highland Mineral	¾ mile east of Poland	Androscoggin	2	45	Carbonated.
20. Poland	South Poland	do	8		Alkaline.
21. Knowlton's Soda	2½ miles south of Strong	Franklin	8		Do.
22. Summit	Harrison	Cumberland	38	46	

Analyses of water from springs in preceding list.

[Parts per million.]

	$CaCO_3$.	$MgCO_3$.	$FeCO_3$.	Na_2CO_3.	$CaSO_4$.	$MgSO_4$.	K_2SO_4.	NaCl.	Fe_2O_3.	Al_2O_3.	SiO_2.	Organic and volatile.	Total.	Analyst.
1 [a]	16.0	1.0	.....	.....	2.0	.....	.....	4.0	3.0	.....	8.0	.....	34.0	E. E. Calder.
2	10.56	5.98	.....	([b])	5.78	.....	.....	2.72	.60	.....	11.50	.....	.....	S. P. Sharples.
2	18.0	5.4	.....	.....	3.6	14.4	3.6	7.2	5.4	.....	14.4	.....	72.0	La Bua.
3	1.688	1.717	.....	.....	1.894	.....	.....	[c] 3.774	.242		6.386	.....	18.757	H. Carmichael.
4	2.72	.11	0.69	1.04	.....	.....	[d] .34	[c] 3.71	.....		4.64	.....	13.25	F. C. Robinson.
5	.....	23.1	13.8	[e] 4.3	.....	.....	[f] 19.7	4.3	10.3	3.4		.....	78.9	R. C. Stanley.
6	25.0	35.0	.....	.....	.....	.....	.....	.....	2.0	2.0	3.0	.....	67.02	S. S. Bradford.
7	5.7	.4	.7	[g] 1.5	.....	.....	[d] 1.3	2.7	.....	.....	7.0	1.7	19.5	F. C. Robinson.
8	25.16	6.09	6.62	.....	5.61	.....	[d] 5.33	[h] 5.0	.....	1.89	20.56	([i])	78.61	W. P. Mason.
9	5.59	3.11	.52	.....	13.09	.....	.....	4.12	.....	8.38	12.44	([j])	48.77	Do.
10	8.0	2.5	.8	4.3	.....	.....	[k] 1.4	1.8	.....	[l] .2	[m] 11.0	([n])	30.0	J. W. Mallett.
12	1.6	2.3	.....	6.0	5.4	.....	.....	1.3	.12		9.0	.....	25.8	S. P. Sharples.
13	8.2	2.5	.....	.....	.....	.....	2.0	14.7	.....		8.6	.....	36.0	F. L. Bartlett.
14	[o] 57.0	[o] 17.3	[o] 46.7	.....	.....	.....	34.0	32.2	.....	Trace.	11.0	([p])	198.2	Do.
15	.....	16.1	14.4	.....	.....	.....	[f] 24.9	8.6	.....	22.3		.....	86.3	R. C. Stanley.

[a] The figures to the left correspond to those preceding the names of springs in list above.

[b] Also K_2CO_3=1.5.
[c] Including KCl.
[d] Na_2SO_4.
[e] Including K_2CO_3.
[f] Including Na_2SO_4.
[g] Also K_2CO_3=.3.
[h] Also KCl=9.9.
[i] Also $NaNO_3$=.91 and $MnCO_3$=.45.
[j] Also $NaNO_3$=1.52.
[k] Also Na_2SO_4=4.6.
[l] $Al(OH)_3$.
[m] Metasilicic acid.
[n] Also $MnCO_3$=.0058 .1; $SrCO_3$=.1; $RbCO_3$=tr.; Li_2CO_3=.05; $NaNO_3$=1.2; Na_3PO_4=.03.
[o] Bicarbonates.
[p] $FeSO_4$=13.9.

Analyses of water from springs in preceding list—Continued.

	$CaCO_3$.	$MgCO_3$.	$FeCO_3$.	Na_2CO_3.	$CaSO_4$.	$MgSO_4$.	K_2SO_4.	NaCl.	Fe_2O_3.	Al_2O_3.	SiO_2.	Organic and volatile.	Total.	Analyst.
16	[a] 7.5	[a] 5.1	.....	[a] 20.5	.....	.....	3.1	4.4	Trace.	Trace.	24.1	.....	64.7	S. D. Hayes.
17	[a] 45.2	[a] 19.2	[a] 28.2	[a] 7.6	9.0	.....	[b] 10.3	15.2	.....	Trace.	Trace.	.....	134.7	Do.
18	18.6	6.7	39.0	277.0	52.5	.....	.....	18.6	Trace.	.....	12.5	Trace.	424.9	H. C. Carmichael.
19	37.4	9.3	.....	.....	.....	.....	17.7	8.1	.....	.....	11.2	.....	83.7	F. L. Bartlett.
20	21.1	9.3	.....	2.3	.....	.....	2.7	4.6	Trace.	Trace.	19.2	4.0	63.2	C. F. Chandler.
21	5.5	2.3	.....	6.4	.....	.....	7.7	4.4	Trace.	Trace.	16.3	.....	42.6	
22	17.0	4.2	.....	[c] 24.0	.....	.....	.....	3.0	Trace.	Trace.	16.7	4.1	.....	F. L. Bartlett.

[a] Bicarbonates. [b] Including Na_2SO_4=4.5. [c] Including K_2CO_3.

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Maine [well and spring records], by W. S. Bayley: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, 1904, pp. 26–55.

NEW HAMPSHIRE.[a]

By M. L. Fuller.

TOPOGRAPHY.

Taken as a whole New Hampshire is more rugged than any other New England State. Although the mountains are lacking in the definite trend which characterizes the Green Mountain and Berkshire Hill ranges, they comprise, nevertheless, the highest and most rugged peaks of the eastern section of the country north of North Carolina. The highest land is in the western and northern parts of the State, culminating in the White Mountains of the north-central portion, where Mount Washington and several other peaks reach elevations of 5,000 to 6,000 feet or over. The lowest area within the State is in the southeastern portion, where much of the land is less than 500 feet above sea level, considerable tracts lie between 500 and 1,000 feet, and a few hills and ridges above 1,000 feet.

In general the hills and mountains present smooth and rounded outlines, while the valleys are generally wide, with gentle or moderate slopes. In addition to the rock hills, there are, in the southern third of the State, a large number of smooth, lenticular hills, 100 feet or more in elevation above their base, composed of deposits formed by the glaciers when they occupied the region. They are known as drumlins.

GEOLOGY.

Over the greater part of the State the rocks are of the crystalline type, and include granites, gneisses, etc., but along the western border, and also along a broken belt extending from the southwestern portion of the State northeastward into Maine, in the vicinity of Rochester, there are extensive outcrops of slates, quartzites, schists, etc., with occasional small areas of limestone. The rocks of all types are generally characterized either by bedding or lamination planes, and are frequently much broken by joints.

Like other New England States, New Hampshire is covered with surface deposits of unconsolidated material laid down by the ice sheet or its associated drainage ways. This surface material or drift is not

[a] The portions of the present descriptions relating to wells and springs are based on data collected by Mr. J. M. Boutwell.

of uniform distribution, being in general of much greater thickness in the southern portion of the State than in the northern. Neither is the drift of uniform thickness in the same general region, the crests and sides of the mountains and many of the higher hills being thinly coated with or even nearly free from glacial materials. In the valleys and on the lowlands, however, the drift deposits reach a considerable thickness and afford the most important source of water in the State.

Of the types of drift the stratified deposits along the present stream channels are the most important. The sands and gravels along the Connecticut, Merrimac, Pemigewasset, Ashuelot, Contoocook, Saco, and Great Ossipee rivers are of considerable importance. Many small areas and a few large ones are covered by deposits laid down in glacial lakes at a time when the retreating ice margin blocked the northward-flowing streams. Extensive stratified deposits also occur along the Atlantic coast in the southeastern portion of the State. Outside of the areas of stratified materials of the river bottoms, glacial lake basins, and along the coast, the surface is generally covered with a bowlder clay, or hard pan, known as till. In general it is very thin, but becomes of considerable thickness in the lenticular hills, known as drumlins, in the southern third of the State.

UNDERGROUND WATERS.

WELLS.

The wells may be grouped into two classes: (1) Those in the drift and (2) those entering the rock. Of the wells in the drift, those in the compact and more or less clayey till or hard pan yield the least satisfactory supplies both as regards quantity and quality. In the stratified drift, especially in the sands and gravels of the valleys and basins mentioned above, the supplies are generally of good quality and ample in volume. In the more densely populated portions of the State, especially near the coast, the shallow drift waters are sometimes liable to pollution, but satisfactory supplies can usually be obtained at almost any point where the stratified drift occurs.

Wells are in general drilled into the rock only when satisfactory supplies can not be obtained from the drift. The rocks over a large part of the area are crystalline and dense and do not present ideal conditions for water storage, so that the value of a rock well must always be in doubt until it is completed. As already pointed out, the crystalline rocks are generally marked by lamination planes and are cut by joints, while the slates, quartzites, limestones, and other stratified rocks are characterized likewise by joints and also in many instances by rather definite bedding planes. The general effect of all of these features is to allow the water to penetrate into the interior of the rock, and most deep rock wells obtain moderate supplies, but irregularities

in the occurrence of joints and other planes render the results of drilling very uncertain.

Many wells from 200 to 1,300 feet deep have been drilled in the State, nearly every county being represented. The majority of these have found water, although a few of the deeper wells have been failures. The supplies in some of these wells are so great as to warrant the installation of steam pumps for raising the water. The deep wells are used mainly in the various manufacturing industries and by the larger hotels.

The waters of the drift are generally soft and relatively free from mineral matter, but those obtained by the deeper rock wells are frequently hard and charged with mineral matter, especially iron.

SPRINGS.

As in all rugged regions, springs abound in the hilly portions of New Hampshire. Over a large portion of the western and northern part of the State there is hardly a farm that is without one or more available springs. In these regions springs are the leading source of domestic supplies, and at a number of places, as at Dover, Gorham, North Stafford, Nashua, Bennington, and elsewhere, springs constitute a principal or partial source of public supply. Spring waters are also frequently used in dairy and other similar industries at many points throughout the State.

Besides the uses outlined above many of the spring waters of New Hampshire are placed on the market for medicinal or table use. In 1902, eight springs reported sales amounting to 629,500 gallons, with a value of $185,995,[a] viz:

Amherst Mineral Spring, Amherst, Hillsboro County.
Granite State Spring, Plaistow, Rockingham County.
Hale Spring, Plaistow, Rockingham County.
Lafayette Spring, West Derry, Rockingham County.
Londonderry Lithia Spring, Londonderry, Rockingham County.
Mount Madison, formerly Gorham Mineral Spring, Gorham, Coos County.
Pack Monadnock Lithia Spring, Temple, Hillsboro County.
Toof's Artesian Well, Concord, Merrimac County.

In addition to the above springs there are probably many local springs which supply water for family use on a small scale in the cities. A number of resorts have also been established at springs.

PRINCIPAL PUBLICATIONS.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

VERMONT.

By G. H. Perkins.

GENERAL CONDITIONS.

Vermont is 157 miles long from north to south and, on the average, about 58 miles wide from east to west. The Green Mountain Range, which divides the State into nearly equal east and west portions, forms a watershed from which most of the streams flow either east into the Connecticut or west into Lake Champlain. As the mountains and foothills occupy a large portion of the State there is little level ground, the surface being mostly uneven—mountain, hill, or valley. The mean rainfall over the State is not far from 39 inches. Probably no State is more abundantly watered, for in most of the towns springs are numerous and unfailing, and these are supplemented elsewhere by wells and streams.

The unaltered stratified rocks of Vermont are found mostly in the Champlain Valley, where the Cambrian sandstone, Beekmantown sandstones and limestones, Chazy, Trenton, and sometimes Black River limestone and Utica shales form a narrow border along the western part of the State. East of these unchanged beds the rocks are largely crystalline and metamorphic, consisting of granite, gneiss, schist, and slate. The whole State is covered with glacial deposits, composed of gravels, clays, and sands.

WATER SUPPLY.

Public supplies.—Because of the abundance of springs and the consequent ease and cheapness with which a public water system can be established in many towns, such supply is often found where it would scarcely be expected. At least 65 towns and villages have a more or less complete public supply. Some of these are owned by the towns, many by corporations or individuals. In a number of towns there are several systems; for example, Barre has at present a system owned by the city, which supplies 1,200 families, and at least 5 smaller supplies, which are used by from 6 to 250 families each. Montpelier is still more lavishly provided, there being the city supply, which furnishes by far the greater number of the residents, and, in addition, more than twelve other sources which supply from 2 to 50 or more

families. In 1898 a State laboratory of hygiene was established, and as water used for drinking can, under certain regulations, be analyzed here free of charge, most of the water used in the larger towns is frequently examined chemically. In the following table are given the sources of supply of most of the important cities and towns of the State:

Sources of water supply of Vermont towns.

County.	Town.	Source of supply.	Ownership.
Addison	Middlebury	Springs	Town.
Do	Vergennes	Otter Creek	City.
Bennington	Arlington	Spring	Arlington Water Company.
Do	Manchester	Equinox Springs; S. M. Orvis's springs	Town.
Caledonia	East Barnet	Springs	Town water company.
Essex	Island Pond	do	Island Pond Water Company.
Do	Lunenburg	Three large springs	
Franklin	Richford	Springs	Town.
Do	St. Albans	Reservoir (4 miles from town).	Do.
Lamoille	Hydepark	Springs	Private.
Do	Jeffersonville	do	Town.
Do	Johnson	do	Waterman & Welch.
Do	do	do	Water company (J. A. Pearl, agent).
Do	Stowe	do	C. E. and F. O. Burt.
Orange	Bradford	A series of springs	Town.
Do	North Thetford	Springs	Union and North Thetford water companies.
Do	do	Union and North Thetford water companies.	Independent farmers.
Orleans	Derbyline	Springs	Town.
Do	Glover	do	Private.
Do	North Troy	do	Two companies.
Rutland	Brandon	Hitchcock Pond (6 miles north).	Town.
Do	Center Rutland	Springs	Do.
Do	Danby	do	Do.
Do	Pittsford	Large spring	Do.
Do	Poultney	Crystal Lake, Hampton, N. Y.	Do.
Do	Proctor	Springs	Do.
Do	Rutland	Mendon brooks	Do.

Sources of water supply of Vermont towns—Continued.

County.	Town.	Source of supply.	Ownership.
Washington	Barre	Several companies	Water company.
Do	do	Springs	Harvey Hersey.
Do	do	Brooks	Private and city.
Do	do	Spring	Barre Spring Company.
Do	Marshfield	Springs	Batchelder Water Company.
Do	Middlesex	do	Private owners.
Do	Montpelier	Berlin ponds (two)	City.
Do	Northfield	Two public systems	Private.
Do	Plainfield	Springs	Village.
Do	Roxbury	do	J. W. Howe and G. A. Tilden.
Do	Waterbury	Brooks and springs collected.	Town.
Do	Waterbury Center	Springs	Hopkins & Company.
Windham	Bellows Falls	Minard's pond	Town.
Do	Jamaica	Fifteen springs	Do.
Windsor	Chester	Stream	Chester Water Company.
Do	Hartford	Springs	A. L. Peace.
Do	Ludlow	do	Town.
Do	Norwich	do	Do.
Do	Rochester	do	Do.
Do	Springfield	do	Do.
Do	White River Junction.	do	Do.
Do	Wilder	Three springs	Olcott Water Company.
Do	Windsor	Springs	Town.

Common springs.—As has been indicated, springs are abundant over a large part of the State. Of the 248 towns reporting, not less than 190 are said to be wholly or in large part supplied from springs. Many of these springs are large and constant in flow and temperature, the latter being often as low as 38° F., even in midsummer, and many show throughout the year a temperature varying but little from 45° F.

As there is little or no soluble matter in the rocks in most parts of the State, the spring water is usually pure and soft.

The abundance of springs is shown in the reports from single and not large farms, that within their limits there are 20, 30, or even 40 active springs. The water supply of most towns having a public water system is taken either from one large spring or from several

which have been connected. Analyses of many of these springs could be given. Nearly all of them, however, simply show pure water with no organic and very little solid matter, and as Vermont is for the most part not thickly settled, there are few or no sources of contamination. As an example of what may be regarded as an average sample of Vermont spring water, the following is given. The sample was taken from a tap located at some distance from the reservoir supplied by springs. It is not the purest nor the worst.

Analysis of water from Johnson, Vt.

	Parts per million.		Parts per million.
Total solids	40.4	Nitrogen as nitrates	.100
Loss on ignition	3.2	Nitrogen as nitrites	None.
Fixed solids	37.2	Hardness	3.1
Free ammonia	.018	Turbidity	None.
Albuminoid ammonia	.07	Sediment	None.
Chlorine	.4	Color	None.

Mineral springs.—Mineral springs are found, though not in large number, in different parts of the State. Most commonly they are more or less sulphurous, but alkaline carbonated springs also occur. The chief resorts on account of the water are Alburg Springs, Highgate, Sheldon, Clarendon, Middleton, and Brunswick. The springs at South Hero, Chelsea, Concord, Wolcott, Newbury, and Warren are all of some repute. The Equinox Spring, at Manchester, is not mineral, but is simply a very fine spring of pure water. The water of some of the deep wells is so strongly magnesian as to properly come under the class of mineral waters.

The springs reporting shipments of water in 1902[a] are as follows:

Brunswick Mineral Spring, Brunswick, Essex County.
Clarendon Springs, Clarendon Springs, Rutland County.
Equinox Spring, Manchester, Bennington County.
Middletown Springs, Middletown Springs, Rutland County.
Missisquoi Mineral Springs, Sheldon, Franklin County.
Newfane or Vermont Mineral Spring, Putney, Windham County.

The amount shipped is stated as 89,100 gallons, with a value of $22,760.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

As examples of these mineral waters the following analyses are given:

Analyses of Vermont spring waters.

Clarendon Spring.	Parts per million.	Missisquoi Spring.	Parts per million.
Sodium chloride	2.5	Free carbonic acid	45.49
Potassium sulphate	2.0	Sodium chloride	.38
Calcium sulphate	.8	Calcium chloride	2.12
Calcium bicarbonate	182.2	Magnesium chloride	.60
Magnesium bicarbonate	36.7	Sodium sulphate	6.52
Magnesium chloride	1.1	Calcium sulphate	12.09
Iron bicarbonate	1.8	Aluminium sulphate	2.70
Silica	11.2	Magnesium sulphate	5.51
Alumina	.8	Sodium phosphate	.08
		Sodium bicarbonate	126.62
		Magnesium bicarbonate	72.19
		Manganous bicarbonate	1.40
		Ferrous bicarbonate	3.03
		Silica	12.25
		Crenic and apocrenic acid	Trace.
		Titanic acid	Trace.

Ordinary wells.—Wells of any sort are less common than they would be if springs did not afford a more convenient and better source of water. Underground water is everywhere and wells can be successfully dug in all parts of the State. Most of the wells thus far dug are not deep, ranging from 10 to 30 feet, and are usually wholly in the drift or other glacial deposits. Occasionally a well is carried down into the underlying rock, but not often.

The water of wells is usually reported as hard and almost always the amount of solids in well water is much greater than in spring water. In some parts of Vermont, as on Grand Isle, it has been found better to dig very large, though shallow wells. Some of these are 16 feet in diameter and 12 to 15 feet deep. In this way more water is procured than would be obtained by making a small well and going deeper.

Deep and artesian wells.—Wells of this class are found most commonly in the Champlain Valley and in the stratified rocks. The water is very often strongly impregnated with alkaline salts, especially of magnesia and lime, and is therefore very hard. Reports have been received from about 100 wells which are over 50 feet deep. This number, however, does not include nearly all there are in the State. The deepest well in the State is one which was bored for experimental purposes rather than water by Dr. W. S. Webb. It is 1,400 feet deep and gives no water, though only 300 feet from the lake shore. A well sunk not far from the shore of the lake by the Burlington Rendering

Company to a depth of 490 feet found no water. In both cases water had to be supplied from outside for the drilling.

Only a few of these wells flow, but in a few the water rises from 4 to 18 feet above the mouth of the well. In or near Burlington there are 16 wells bored to depths of from 130 to 496 feet. At least 5 of these are so strongly impregnated with lime and magnesia salts that they can not well be used for steam, since the precipitation of these salts fills the pipes. The water in these wells is clear and cold and is much liked for drinking. It has been found very beneficial in some cases of dyspepsia.

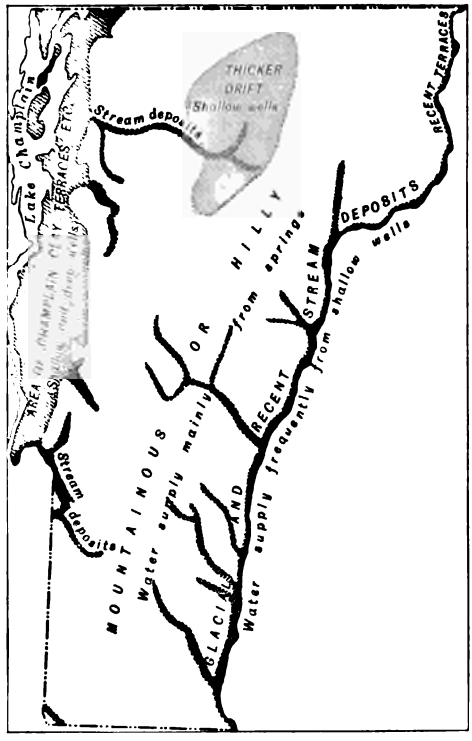

FIG. 16.—Water-bearing drift deposits of Vermont.

The character of the beds passed through by these wells was much the same, but the thickness of each bed varied greatly; that is, the first beds were glacial and the last were Cambrian or Lower Beekmantown, but in one well the glacial beds are only 20 feet thick, while in another they are over 200. In the slate region, which is Cambrian, there are more deep wells than in any other part of the State. Mr. J. P. Hoadley, who has bored more wells than anyone else in the State, tells me that he has bored over 50 in the town of Poultney alone. Probably no other town has so large a number. As has been noticed, most of the deep wells are near the western border of the State, in the towns bordering Lake Champlain. The usual cost of boring deep wells in this State is from $1 to $5 per foot.

Lakes and ponds.—Naturally many of those who live near Lake Champlain take water from it by windmill or, more rarely, by steam pump. The only town that takes its supply from the lake is Burlington, the largest place in the State. Here the water is pumped by steam to two large reservoirs, nearly 400 feet above the lake, from which it goes by gravity over the city.

An average analysis of the water of Lake Champlain taken from faucet is as follows:

Analysis of water of Lake Champlain.

	Parts per million.		Parts per million.
Total solids	74.1	Nitrates	0.128
Loss on ignition	18.0	Nitrites	.00
Fixed solids	56.1	Sediment	([a])
Free ammonia	.035	Turbidity	([a])
Albuminoid ammonia	.143	Hardness	4.3
Chlorine	.68		

[a] Very slight.

A few towns, as, for example, Brandon and Bellows Falls, get water from small lakes or ponds. Some of these ponds are directly fed by springs and are therefore very satisfactory as a source of supply.

Streams.—A few towns—Vergennes, Wells River, and some others—get water from adjacent streams. There seems to be more danger of contamination in this case, and the supply is therefore less satisfactory.

Cisterns.—Cisterns are not much used in this State, but there are some places in which the only other supply is from wells which give hard water, and in these places cistern water is used for drinking and laundry. The whole number of towns reporting cisterns in use is very small.

SUMMARY.

It will be seen from the foregoing statements that the questions which the necessity for wholesome and abundant water for domestic purposes raise in many parts of the country are not important in Vermont. Everywhere, except in a few places, water is abundant in quantity and excellent in quality. Many towns allow a large quantity of cool, clear, pure spring water to run to waste because there is no use for it. But the conditions under which this ample supply exists are extremely interesting and deserve extended study.

As has been noted, most of the wells and springs are located in the glacial deposits. These are often very thick. Some of the wells have gone through 200 feet or more of these deposits before reaching the underlying rock. For example, one of the four deep wells at Fort Ethan Allen was bored through 221 feet of sands and clays and then went over 150 feet into the ledge below. Few wells except those of considerable depth go into the rock. Most either stop in hardpan some distance above the rock or go just to the ledge, but rarely into it, and in those cases where, in the hope of getting more water, the

rock has been entered, the result has not always been satisfactory, no increase in amount of water being gained. In some wells that have been carried a short distance into the rock more and better water has been obtained, but such cases are the exception. The above applies only to shallow wells. In the deep wells often the volume of water flowing has been increased by boring deeper. This is, however, by no means always true. In the reports of several deep wells we find that as much or more water was found at 200 feet as at 300 or more.

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MASSACHUSETTS AND RHODE ISLAND.

By W. O. Crosby.

Since Rhode Island is half encircled by Massachusetts and presents no essentially distinctive topographic or geologic features, the two States may best be treated as a unit in a preliminary study of their underground waters.

GEOLOGY.

In a broad way Massachusetts and Rhode Island may be subdivided, according to the relief of the land, into a number of belts, each marked by its own characteristic geology and topography. The westernmost of these may be termed the Berkshire Hills. These are a series of high mountainous ridges lying in the extreme western part of the State, the rocks of which consist of strongly folded and faulted quartzites, limestones, slates, schists, etc., mostly of Paleozoic age, which by their erosion have given rise to the rugged topography characterizing the region. To the east the Berkshire Hills grade off into a less rugged and somewhat lower region of similar rocks and structure, which extends to the borders of the Connecticut Valley lowlands. These lowlands are marked in general by the presence of soft reddish Triassic sandstones and shales, with an occasional trap bed forming the ridges. They extend from the Connecticut line, where they have a width of 20 miles or more, northward to their termination, a few miles south of the New Hampshire line. East of the Connecticut Valley a belt of folded sedimentary or metamorphic rocks is first encountered, beyond which the broad crystalline belt, consisting largely of igneous rocks, but including many altered sedimentary beds, extends eastward to the coast. In the vicinity of Boston, and extending southwestward for some distance, and again in the vicinity of Narragansett Bay, and in the region to the northeast, there are considerable areas of Carboniferous sandstones, conglomerates, and slates. Cape Cod and a portion of the adjacent region consist superficially entirely of gravel, sands, etc., of glacial derivation.

Over the whole of the surface of the State is spread a mantle of drift left by the glaciers which once covered the region. This is of

two types, a distinction being made between till, bowlder clay, or hardpan, as it is variously known, and the different forms of stratified drift, including, besides more or less distinctly stratified gravel and sand, large amounts of bedded clay or rock flour. The till is a nearly universal deposit. It attains its greatest average thickness on the upland surfaces, and its maximum thickness in the rounded hills known as drumlins and in moraines left by the ice sheet which once covered the region. In the valleys and over the lowland generally the till is to a large extent covered and concealed by the stratified drift. Except in moraines, the till is prevailingly well compacted, a true hardpan, and contains enough clay and rock flour to make it essentially impervious. Hence, save where it contains layers of gravel or sand, it must be reckoned as an unreliable water horizon as far as large volumes are concerned, but it is nevertheless the source of supply of thousands of small wells used for domestic and farm purposes. Its chief function, however, is to impound and to control or direct the movement of the water of overlying sands and gravels.

Of the stratified drift, the coarser phases, including the gravel and sand and much of the rock flour, are confined chiefly to the valleys and to the lower portions of the surface, occurring largely as overwash and delta plains, formed by glacial streams.

WATER SUPPLIES.

AREAS CONSIDERED.

The drift is by far the most important and reliable source of underground waters, and this fact makes the tracing and detailed mapping of these deposits a matter of special interest. The principal areas only may be mentioned here. These are the Berkshire Valley; the valleys of the Connecticut and its principal tributaries, where the flood plains and terraces have their chief development; the Nashua Valley, with the delta plains, etc., of glacial Lake Nashua; the Merrimac Valley, with widespread delta and overwash plains; the Boston basin, with the delta plains formed at many different levels in the series of glacial lakes once existing there; the overwash and other plains of the Blackstone Valley and the basin of Narragansett Bay; the widely-extended plains of varied origin in southeastern Massachusetts and on Cape Cod north of the inner moraine; the overwash or apron plains of the inner moraine on Cape Cod, east of Woods Hole; and the similar plains of the outer moraine, on the south sides of Marthas Vineyard and Nantucket.

The Pleistocene or glacial clays are normally composed in large part of rock flour; but in spite of this fact they must be regarded as practically impervious and of no interest as available sources of underground water, ranking even below the till in this respect. It is

fortunate, therefore, that the glacial clays have deen deposited at relatively low levels and in the coastal areas, mainly below sea level. Water is occasionally obtained from sand or gravel underlying the clays, in which case it may have considerable head.

BERKSHIRE VALLEY.

This is an area of complexly folded and faulted sedimentary formations, mostly of early Paleozoic age, including in succession a basal Cambrian quartzite outcropping along the east side of the valley, the great crystalline Cambro-Ordovician limestone forming the floor of the valley at most points, and the metamorphic slates and schists of the Greylock and Taconic ranges. Although the quartzite is in part of a distinctly friable and permeable character, as is so well shown where it is quarried as a glass sand, and is, therefore, entitled locally to some consideration as a water horizon; the topographic relations of the limestone to the valley, regardless of other considerations, determine it as the chief bed-rock source of water. Its crystalline texture makes the limestone practically impervious and limits its water-bearing capacity to joints and fault fissures, which, however, may be appreciably widened by solution. The structure is not very favorable to artesian flows, except perhaps very locally. Though somewhat uncertain in its occurrence water is usually found in the deeper wells. It is possible that borings through the limestone at certain points might develop artesian sources in the underlying quartzite. The rock waters of the Berkshire Valley are, in general, distinguished by their hard or calcareous character, and considerations of quantity and quality combine to make them relatively unimportant.

The drift of the Berkshire region is chiefly till, and the stratified drift is mainly confined to the bottoms of the valleys, being most abundant, as a rule, where the valleys are broadest, as in the latitude of Williamstown and North Adams, at elevations below 860 feet; of Pittsfield and Richmond, mainly below 1,000 feet; and of Lenox and Lee, where existed glacial Lake Housatonic at an elevation of about 1,000 feet. South of Great Barrington the stratified drift, with a normal elevation of 700 feet, and a breadth varying from 1 to 2 miles, is continuous to the State line and beyond. The topographic relations of these deposits insures to them not only the precipitation belonging to their areas, but also a large part of the rainfall on the bordering slopes of till, and since their own contours determine a shallow water table, it follows that they must be regarded as very important and readily available reservoirs of the ground water. As in other limestone regions, the drift is more or less calcareous, as is evidenced at times by its local cementation, but rarely to such a degree as to make the water sensibly hard.

CONNECTICUT VALLEY.

The great thickness in this valley of arenaceous strata, characterized throughout by moderate monoclinal dips, is very suggestive of artesian conditions. It does not appear, however, that this can fairly be described as an artesian basin, although in many wells the water rises nearly to the surface and occasionally flows. The best wells are in the sandstone areas. In the conglomerate or arkose areas even the deep wells sometimes fail to obtain water. The waters are always hard, especially in the shales, and it is frequently impossible to use them in boilers.

The drift of this great valley, as previously noted, is chiefly stratified, the unmodified drift or till being almost entirely restricted to the lenticular hills or drumlins, of which there are several notable groups; and the modified or stratified drift, occurring in the forms of lake beds, deltas, terraces, and flood plains, attains in places, and especially in the axis of the valley, a considerable thickness. In fact it is one of the principal storage reservoirs of New England, a large majority of the successful wells, as well, probably, as most of the springs, deriving their water from it. Over a large part of the valley, and especially on the low-lying plains as distinguished from the terraces, the water table is near the surface, and shallow wells afford an unfailing supply. The drift waters are nearly always soft.

EASTERN AND WESTERN HIGHLANDS.

The western highlands include the elevated hilly region between the Berkshire Hills and the Connecticut Valley belt, while the eastern highlands embrace the similar but less hilly region to the east of that valley.

The two regions are alike in having igneous and metamorphic bed rock, thinly covered with till on the uplands. The modified drift is confined chiefly to the valleys and is naturally most abundant in the broader valleys of the eastern highlands. This is, as usual, the chief and most available source of the ground water; and it is partly for this reason that we find the population massed upon it, the till of the uplands, as a rule, supporting only a sparse farming population. During the recession of the ice sheet the conditions favored the development of temporary glacial lakes in the valleys, especially of the eastern highlands, and at all elevations up to 1,000 feet or more; and thus may be explained bodies of modified drift of exceptional volume and depth, lying sometimes at such elevations as to make them important storage reservoirs for ground water.

Although everywhere relatively superficial, the ground water is naturally pure and soft, and a study of the topographic map shows

relatively little obstructed drainage with consequent swampy conditions and peaty waters. On the other hand, the frequently dense village populations on the narrow and shallow valley deposits of sand and gravel present conditions especially favorable to contamination of the ground water and suggest the introduction of a public supply from similar deposits farther up the valley, or from the surface streams or ponds of the uplands. The till of the uplands, derived from metamorphic and highly quartzose formations, is doubtless of an exceptionally arenaceous and porous texture, and this feature, supplemented by occasional interbedded and superficial layers of washed material, will readily account for the water supply, often copious and excellent, of the farms.

NASHUA VALLEY.

This valley is excavated along a belt of altered slaty rocks in northeast Massachusetts. It is a relatively limited and simple tract, lying in the valley of the northward draining Nashua River, and hence presenting exceptionally favorable conditions for the development of glacial-lake phenomena, including broad and deep deltas or sand plains. These occur at various levels, but are rather limited in extent above 440 feet, and have their chief development below 370 feet. Above the lake levels stratified gravels and sands occur but scantily, and the till or hardpan, derived largely from slaty rocks, is of a relatively argillaceous and impervious character.

Bed-rock wells, whether sunk in the slaty rocks or in the bordering schist and granite, must in general be of little value, and, as on the highlands, artesian conditions do not exist except perhaps very locally, where the rocks are traversed by favorable fissures.

COASTAL LOWLANDS.

In density of population and consequent demand for water this area leads all the rest. But the concentration of the population in cities necessitates the extensive utilization of surface waters, while the ground waters have been found available chiefly for the smaller communities and private interests. This is a region of crystalline, igneous, and metamorphic rocks, with the exception of the sedimentary deposits, chiefly conglomerates and slates of Carboniferous age, of the Boston, Norfolk, and Narragansett basins. Deep rock wells are more common in this region, especially in the vicinity of Boston, than in any other part of New England. On the crystalline formations the proportion of decidedly successful wells is not large, and the result of a boring can not be predicted. In the Carboniferous slates, as proved by numerous examples in Boston, Cambridge, etc., there are very few successful wells, the water being almost invariably inferior in both quality and quantity. In the conglomerate series are

many good wells and comparatively few failures. In no case, probably, are the rock waters yielded chiefly by interstitial flow; the good wells are those that intersect favorable systems of joints and other fissures, and in this connection it may be noted that the joint structure of the conglomerate is exceptionally distinct and open.

This is a region of abundant drift deposits. The stratified drift, including sand and gravel which is largely referable to glacial lakes or local apron plains, is widespread and, as usual, is the principal source of the ground water, supplying even some of the larger cities, such as Lowell and Providence. These deposits, as previously noted, become more continuous southward in the region of Narragansett Bay and Cape Cod Bay, and attain, no doubt, a considerable thickness. They may be regarded as a vast and practically inexhaustible reservoir of water, which, with a uniformly shallow water table, is readily available by pumping and far exceeds in quantity the demands of the present population. These statements may be repeated for the great apron plains south of the terminal moraine, on the south side of Cape Cod, and on Marthas Vineyard and Nantucket.

NORMAL CHLORINE.

The normal chlorine, or maximum proportion of chlorine (present as common salt or sodium chloride) which may exist in an uncontaminated water, usually varies inversely as the distance from the sea, the range for Massachusetts being from 2.42 parts per 100,000 at Provincetown and 2.16 parts on Nantucket to 0.06 parts in Berkshire County. The normal chlorine not only depends upon the proximity to the coast, but it is highest on the salient and most exposed parts of the coast, where the surf breaks heavily and the salt spray is wafted inland most freely. Higher amounts than those indicated are due either to peculiarities of the rocks or drift from which the water comes or to pollution by sewage. In New England it is commonly the latter which gives rise to high chlorine, and waters containing this constituent in amounts distinctly above the normal should be avoided for domestic purposes.

MINERAL SPRINGS.

MASSACHUSETTS.

Massachusetts has the distinction of possessing a larger number of springs from which waters are shipped than any other State in the country. In 1902 there were 75 such springs that reported shipments, the next largest number being 56, in New York. One reason for the large number of springs reporting sales lies in the fact that many of them are located near cities in which the demand for spring waters for table purposes is very large. The total sales in the year mentioned

amounted to 8,475,365 gallons, having a value of $562,973. Following is a list of the springs reporting:[a]

Abbotts Spring, Methuen, Essex County.
Arctic Polar Spring, Spencer, Worcester County.
Ballardvale Lithia Spring, Andover, Essex County.
Beach Hill Spring, Stoneham, Middlesex County.
Beaver Dam Spring, Scituate, Plymouth County.
Belmont Crystal Spring, Belmont, Middlesex County.
Belmont Hill Spring, Everett, Middlesex County.
Belmont Natural Spring, Belmont, Middlesex County.
Berkshire Crystal Spring, Sheffield, Berkshire County.
Berkshire Sodium Spring, Sheffield, Berkshire County.
Bodwell Spring, Lawrence, Essex County.
Burnham Spring, Methuen, Essex County.
Chapman's Crystal Mineral Spring, Stoneham, Middlesex County.
Crystal Mineral Spring, Methune, Essex County.
Crystal Spring, Brockton, Plymouth County.
Deep Rock Spring, Lynnfield Center, Suffolk County.
Diamond Spring, Lawrence, Essex County.
El-azhar (formerly Sheep Rock) Spring, Lowell, Middlesex County.
Electric Spring, Lynn, Essex County.
Everett Crystal Spring, Everett, Middlesex County.
Farrington's Silver Spring, Milton, Norfolk County.
Fulton Natural Spring, Medford, Middlesex County.
Garfield Spring, Weymouth, Norfolk County.
Geddes Mineral Spring, Marlboro, Middlesex County.
Goulding Spring, Whitman, Plymouth County.
Highland Spring, North Abington, Plymouth County.
Howe Spring, Millbury, Worcester County.
Howland Spring, Dartmouth, Bristol County.
Hygeia Artesian Well, Springfield, Hampden County.
Ingersoll Grove Spring, Springfield, Hampden County.
Katahdin Spring, Lexington, Middlesex County.
King Philip Spring, Mattapoisett, Plymouth County.
Läkoo Indian Crystal Spring, Lawrence, Essex County.
Lang Moore Spring, Natick, Middlesex County.
Larchmont Spring, Lexington, Middlesex County.
Leland Spring, Natic, Middlesex County.
Lexington Spring, Lexington, Middlesex County.
Linden Mineral Spring, Linden, Middlesex County
Lovers' Leap Springs, Lynn, Essex County.
Magnolia Spring, Gloucester, Essex County.
Massasoit Spring, West Springfield, Hampden County.
Middlesex Mountain Spring, Medford, Middlesex County.
Milton Spring, Milton, Norfolk County.
Monatiquot Spring, South Braintree, Norfolk County.
Moose Hill Spring, Swampscott, Essex County.
Mount Blue Spring, Hingham Center, Plymouth County.
Mount Holyoke Lithia Spring, South Hadley, Hampshire County.
Mount Orient Spring, Pelham, Hampshire County.
Mount Pleasant Spring, Lowell, Middlesex County.

[a] Peale, A. C., Mineral waters U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

Mount Washington Cold Spring, Chelsea, Suffolk County.
Myles Standish Spring, South Duxbury, Plymouth County.
Nashoba Minerel Spring, Westford, Middlesex County.
Nemasket Springs, Middleboro, Plymouth County.
Nobscot Mountain Spring, Framingham, Middlesex County.
Norwood Spring, Norwood, Norfolk County.
Pearl Hill Mineral Spring, Fitchburg, Worcester County.
Pepperell Mineral Spring, Pepperell, Middlesex County.
Pequot Spring, North Natic, Middlesex County.
Purity Spring, Spencer, Worcester County.
Ravenwood Spring, Gloucester, Essex County.
Robbin's Spring, Arlington Heights, Middlesex County.
Sager Spring, Danvers, Essex County.
Sand Spring, Williamstown, Berkshire County.
Shawmut Spring, West Quincy, Norfolk County.
Silver Seal Spring, Woburn, Middlesex County.
Simpson Spring, South Easton, Bristol County.
Smiley Spring, Haverhill, Essex County.
Steavens's Spring, Lawrence, Essex County.
Sunnyside Spring, Franklin, Norfolk County.
Swampscott Spring, Swampscott, Essex County.
Trapelo Spring, Belmont, Middlesex County.
Undine Crystal Spring, Brighton, Suffolk County.
Valpey Spring, Woodland, Lawrence, Essex County.
Whitman Spring, Whitman, Plymouth County.
Wilbraham Mountain Spring, Wilbraham, Hampden County.

RHODE ISLAND.

The number of springs reporting sales in 1902 in this State is four. They are as follows:

Berry Spring, Pawtucket, Providence County.
Gladstone Spring, Narragansett Pier, Washington County.
Holly Mineral Spring, Woonsocket, Providence County.
Ochee Mineral and Medicinal Springs, Johnston, Providence County.

The total sales reported amount to 244,212 gallons, having a value of $26,588.[a]

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[a] Peale, A. C., Mineral waters U. S. for 1902, U. S. Geol. Survey. 1904, p. 996.

CONNECTICUT.

By H. E. Gregory.

A study of the water resources of Connecticut, based on a large number of records of wells and springs, shows that next to rainfall the nature of the rocks or deposits is the factor of greatest importance. In fact the character and availability of the water supply are directly dependent upon two geologic factors—the composition of the rock or other material, and the number of fault or joint fissures it may possess.

RAINFALL.

The annual rainfall in Connecticut is 46.89 inches. This is distributed throughout the year as follows: January, 4.28; February, 3.94; March, 4.23; April, 3.53; May, 4.03; June, 2.95; July, 4.42; August, 4.30; September, 3.34; October, 4.04; November, 4.48; December, 3.44. This is sufficient, when taken in connection with small evaporation, to form a constant supply for the streams of the State, which carry off about 40 per cent of the water that falls, and to furnish abundant ground water. So that, so far as Connecticut is concerned, the available water supply depends on the capacity of the rock and the surface cover of land waste to hold the water.

GEOLOGY AND WATER SUPPLY.

Geologic subdivisions.—As to the characteristics of rock structure which affect underground water, Connecticut is divided into three parts: The limestone (Stockbridge dolomite) area of the upper Housatonic Valley, the Triassic sandstone area of the Connecticut Valley lowland, and the crystalline area of metamorphic rocks occupying the remainder of the State. A small area in the valley of Pomperaug River has the same characteristics as the Connecticut Valley lowland. The map, fig. 17, shows the distribution of the different classes of rock.

Limestone area.—The parts of the State underlain by the limestone are not densely populated. They contain no large cities, and the chief pursuits are dairying and mixed farming. The limestone rock varies greatly in its water-bearing capacity, and wells have usually to be sunk to a considerable depth before a supply is assured. Of nine wells selected as typical, four are over 150 feet in depth (155, 171, 182, 210

feet, respectively), and only one is less than 50 feet. When wells are sunk this deep the supply is plentiful and does not vary with the seasons. The water is hard, containing calcium, magnesium, and iron. The springs issuing from rock in the limestone area show abundant, constant flow and low temperature. In one case an invariable temperature of 45 degrees is reported.

Triassic sandstone area.—The bed rock of the Connecticut Valley lowland is sandstone with interbedded basalts and intruded diabases. The sandstone varies in texture from coarse conglomerate to fine clay shales and is sufficiently porous to hold 20 to 30 per cent of its volume of water. For this area it seems to be true that the deeper the well the more abundant the water supply down to about 500 feet, and that

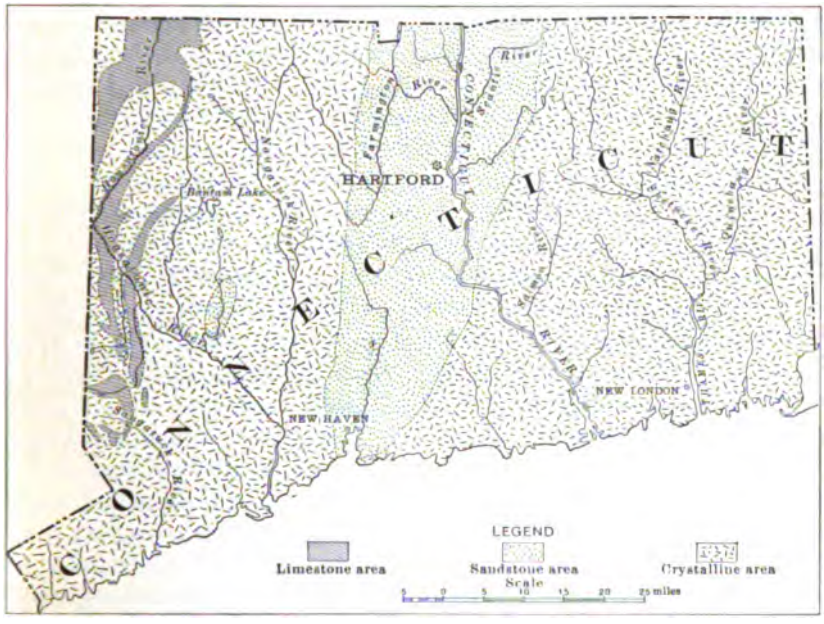

FIG. 17.—Areas of limestone, sandstone, and crystalline rock water supplies of Connecticut.

there are no distinct water-bearing beds. Wells are all deep, averaging for the whole area over 100 feet. One well at New Haven was sunk to a depth of 4,000 feet by the Winchester Arms Company in an unsuccessful effort to obtain a flowing well. The conditions for artesian water are better in the Triassic rocks than elsewhere in Connecticut, but are very unfavorable. While it is true that the sandstones contain abundant water, yet their composition, texture, and position are extremely irregular. They are not arranged in definite series, and they have been shattered by the forces which produced the faults in the valley. There is, therefore, no continuity of stratification and no arrangement of water-bearing beds favorable for artesian wells. The practice among well drillers in Triassic rock is to sink the well

20 to 50 feet below the first supply of water, so as to have a reservoir below. Most of the deep-drilled wells afford a constant supply, but two wells show a decrease and five an increase since they were made. The cost of 60 selected wells averages $280.80, and the cost of pumping apparatus $240.20. More than half of the wells in sandstone supply hard water. Springs in the sandstone area that are known to issue from rock come up along deep-seated cracks and are much colder than the springs formed in glacial materials.

The Triassic area, although it constitutes one-fifth of the State, contains one-third of the population and the most productive farms (averaging $20 per acre in annual value of crops), as well as the largest cities. It is the tobacco center, the manufacturing center, and the railroad center of the State, and is steadily increasing in population. The water supply is the best in the State, but because of the growing population it is becoming an important economic problem. At present the large cities are supplied by lakes and other surface waters, in some cases brought from considerable distances. These supplies are not inexhaustible and studies of other sources are being made. The very marked difference in character and density of population in the Connecticut Valley lowland and the crystalline highland is due partly to the conditions which control the water supply.

Crystalline area.—As shown on the map the area underlain by metamorphic crystalline rocks constitutes a large portion of the State. These rocks are remarkably variable in texture, are folded, twisted, broken, and cut by ancient intrusions and veins, and do not furnish favorable water-bearing conditions. Moreover the run-off constitutes a larger part of the rainfall than in the sandstone or limestone areas. The wells for which records are collected in the crystalline rocks (gneiss, mica-schist, etc.) average 125.8 feet in depth, and the principal water horizon lies 107 feet below the surface. Some of the deepest wells show no water below the first water horizon. Of 34 typical wells, 25 contain hard water, 2 show sulphur traces, 4 iron. The average cost of drilling these wells is $678 and of the pumping apparatus, $162. Some wells have been sunk in the crystalline area which have resulted in complete failure after the expenditure of thousands of dollars. The conditions governing the flow of underground water in metamorphic rocks are not well understood, and it is hoped that arrangements can be made to investigate the water resources of this area, especially along the coast line, where the summer population is increasing yearly.

Springs in the crystalline area known to issue from rock are fairly abundant and yield an unfailing supply. Nearly all of those which have been examined are located along lines of faulting and, judging from their constant low temperature, come from considerable depth.

With the exception of the valleys possessing water power, the crystalline area is given over to mixed farming, and the population is

scattered and in many places is decreasing. The State of Connecticut has added 162,000 to its population in the last ten years, yet during that time 55 townships located on the crystallines have decreased in population. One whole county (Tolland) showed a net decrease of about 1,400 between the years 1890 and 1900. The value of farm products on the crystalline uplands has increased somewhat during the past decade, yet it barely exceeds $10 per acre, and the proportion of improved land to total area is less than 10 per cent.

Faults.—Connecticut is traversed by sets of fault planes running in three or four principal directions. The breaks have produced profound effects on the topography and exert a marked influence on the water resources. They control in part the direction of Connecticut rivers and are the chief cause for the many deep, cold springs of the State, and especially of the mineral springs used for table waters. The springs near South Britain, those which supply water to the village of Collinsville, and the Stafford springs are examples of those which are believed to owe their origin to deep-seated fault cracks. Springs from such deep sources form valuable water supplies and a study is being made of their distribution and character and of means for their fuller utilization.

Water supply of the drift.—The entire State of Connecticut has been overridden by the ice of the Glacial epoch, and this fact has greatly affected the water supply. The numerous lakes, ponds, swamps, and many of the smaller streams owe their position and their very existence to the continental ice sheet. Of particular value to man are the hundreds of lakes, which constitute the principal water supply for cities and villages. The soil of Connecticut also dates from the Glacial epoch, and its character as a water bearer is determined by this circumstance. The bed rock is covered nearly everywhere by one of two kinds of glacial material: (1) Till, which was deposited directly by the ice, and which is a heterogeneous, unassorted mass of bowlders of different sizes embedded in clays of variable texture and composition; (2) stratified drift, which is made up of sands, gravels, and clays, sorted as to size and deposited in layers, and which owes its structure to the fact that it was deposited by water.

The till occupies all the highlands of the State, forming a mantle, usually but a few feet in thickness, over the crystallines and over the trap ridges of the Triassic area. Wells in till are usually shallow, rarely over 50 feet in depth, and it is the practice to sink them but a few feet below the principal water horizon. Seventeen wells are reported as being less than 10 feet in depth and yet containing an abundant supply of water. In general, the wells of the till area contain soft water, which varies in amount with the seasons. During an unusually dry summer the wells in some sections dry out entirely. The till-covered crystallines are being occupied by hotels, sanitariums,

and country estates, and the problem of the increased water supply for these is becoming more and more important.

The springs of the till area furnish prevailingly soft water, and, like the wells, show their connection with the rainfall by their variation from year to year and from season to season. Except in extraordinary years the variation is slight, because the Connecticut rainfall is evenly distributed throughout the year. (Rainfall at New Haven: Spring, 11.67 inches; summer, 12.79; autumn, 11.67; winter, 11.84.)

Stratified drift forms the cover over a large part of the sandstone district, and also occupies the valleys in the crystallines. It varies in depth from only a few inches to over 500 feet, and because of its prevailingly loose texture forms a water reservoir of great capacity. On the New Haven sand plain and in general throughout the Connecticut Valley lowland, water maintains a permanent level 20 to 30 feet below the surface, and the practice is to sink the wells to some distance below this water horizon, so that a reserve supply is always on hand. Where large quantities of water are required for boilers, manufactories, swimming pools, etc., several wells are sunk in close proximity and connected with one pump. Yale University uses 34 such wells to supply water for the gymnasium. The wells in the stratified drift, for the most part, furnish pure water and indicate an available supply which may be used as the cities increase in size. Wells are nearly all driven, and cost on an average $348. The pumping apparatus costs on the average $250. Springs in stratified drift are not numerous, and they vary in size according to the relative thickness and position of the sand and clay layers. Many are wet-weather "seeps;" others furnish sufficient supply for a farmhouse; a few, like the Pequabuck Spring, near Bristol, have sufficient water to form a brook.

Mineral springs.—Fourteen springs in the State furnish water for table use and for medicinal purposes. The Arethusa Spring, at Seymour, which is perhaps best known, marketed 38,000 gallons of water in 1902. Extreme purity is the chief characteristic of the springs located along fault lines, although in a few cases the analyses show the presence of lithium, magnesium sulphate, and other ingredients which give them medicinal values. The pure and abundant spring water is an extremely valuable commercial asset for the State.

The springs reporting sales in 1902 are given in the following list. The total output is reported as 307,000 gallons and the value as $194,085.[a]

Althea Springs, near Waterbury, New Haven County.
Arethusa Spring, Seymour, New Haven County.
Aspinock Mineral Springs, Putnam Heights, Windham County.
Cherry Hill Spring, Hamden, New Haven County.
Granite Rock Spring, Higganum, Middlesex County.
Live Oak Spring, Meriden, New Haven County.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

Mohican Spring, near Bridgeport, Fairfield County.
Oxford Mineral Spring, Oxford, New Haven County.
Park Spring, Willimantic, Windham County.
Puritan Spring, Norwich, New London County.
Stafford Mineral Spring, Stafford Springs, Tolland County.

Each year more land of the till-covered uplands, which has proved unprofitable for farming, is being purchased for country residences and large estates. For these purposes an abundant supply of water of unquestionable purity is indispensable.

It is of scientific interest that the Indian Rock spring water at New Milford and also the surface water at New Haven have been shown to be radio-active.

With the exception of the medicinal waters the Connecticut supply is used almost entirely for domestic and manufacturing purposes, and for these uses is uniformly good. Very rarely are wells or springs or surface supplies unfit for domestic use and only a few manufacturers report water unsuited for boilers or for washing fabrics.

Stream supplies.—The larger rivers of the State are not at present directly available as water supply because the sewage and refuse from manufacturing establishments are emptied directly into them. They thus stand as a large unimproved resource which may be developed whenever the demand for increased domestic water supply justifies the expense of installing plants for the purification of sewage.

Irrigation.—Irrigation is practiced to a small extent in Connecticut, and wherever used the results more than justify the expense. There are but few crops which have all the water necessary for their maximum yield. Hay, in particular, needs abundant water, and is one of the most valuable crops of Connecticut. There is no doubt but that the yield of most field crops could be greatly increased both in acreage and amount per acre by the use of water. The valleys of the crystalline uplands which are now sparsely settled are particularly adapted to irrigation, and it seems evident that a more intelligent use of the soil, the woodlands, and the water resources of the State could win the unimproved and abandoned lands to profitable agriculture.

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NEW YORK.

By F. B. Weeks.

In the State of New York, as in other regions where there is no considerable variation in the amount of rainfall or in the rate of evaporation, the occurrence and character of the underground waters are very largely determined by the topography, by the character of the soil and underlying rocks, and by the structural features of the strata.

PHYSIOGRAPHY.

The State may be divided into five distinct physiographic provinces, viz, (1) Adirondack, (2) Eastern (Taconic), (3) Catskill, (4) Allegheny Plateaus, (5) Ontario. The Adirondack province is the only one lying wholly within the State, the others forming parts of larger topographic divisions which extend beyond its limits.

1. The Adirondack province, second in size, comprises a mountainous area flanked on all sides by a lower, hilly country. It is drained by headwaters of streams flowing into St. Lawrence, Hudson, Black, and Mohawk rivers.

2. The eastern (Taconic) province in its northern part is hilly or mountainous, being formed by the Taconic ranges, which extend into Vermont and Massachusetts, while in its southern part it becomes more gently undulating. It is principally drained by short streams flowing into the Hudson.

3. The Catskill province is composed in part of folded rocks of the northern extension of the eastern Appalachian ridges, and in part of horizontal rocks, and on the west merges into the Allegheny Plateaus province. This region has been deeply dissected by streams which flow into Hudson, Delaware, and Susquehanna rivers.

4. The Allegheny Plateaus province occupies one-third of the State, comprising the area south of the Ontario province from Lake Erie to the Catskills. It contains a number of broad river valleys and is drained by streams that flow into Susquehanna, Allegheny, and Genesee rivers.

5. The Ontario province extends in a rather narrow band around Lake Ontario from the Niagara to the St. Lawrence and is drained by

short streams, some of which form the outlets of the so-called Finger lakes.

The accompanying map (Pl. V) shows the main drainage lines in the State and from these the outlines of the several physiographic provinces may be deduced. The distribution and lithologic character of the several geologic systems represented in the State have been indicated, except the Quaternary. Those springs which are of commercial value are also noted on the map. They include all springs thus far reported whose waters are sold or used in connection with manufacturing enterprises or public water supply.

GEOLOGY AND UNDERGROUND WATERS.

The underground waters will be discussed under the several geologic divisions.

Pre-Cambrian.—The pre-Cambrian system is composed of ancient crystalline rocks and of more or less metamorphosed stratified rocks which can not readily be separated from them. Pre-Cambrian rocks form the greater part of the Adirondack region and also outcrop in the southeastern part of the State. No distinct water-bearing beds occur in these rocks, since the most of them are not stratified or have been so greatly compressed and folded that the stratification planes are no longer even approximately horizontal. The ground water descends along fracture planes and can be obtained at various depths.

In the Adirondacks there are a great number of springs, such as are common in mountainous areas. They are the sources of the many streams that drain the region. The inhabitants depend very largely upon streams and springs for domestic and stock-water supply. The few wells reported obtain their water from sands and clays overlying the hard rocks. In the southeastern part of the State the pre-Cambrian system consists of granites, gneisses, and metamorphic rocks, compressed into folds which have a northeast-southwest direction, and which outcrop in New York, Orange, Putnam, and Westchester counties. In Putnam and Westchester counties several springs having a flow of 100 to 300 gallons an hour, and many smaller springs are reported. The water from a few of them is bottled and sold. Records of deep wells up to 250 feet have been obtained. The deep wells are pumped by windmills or other power and furnish from 30 to 250 barrels a day. The waters of these wells are usually soft. By far the greater number of wells are dug or blasted in rock. These are from 6 to 50 feet deep, and three-fourths of them are said to fail during protracted droughts. The water is frequently reported as alkaline.

Cambrian.—The Cambrian limestones and slates extend in a long, narrow band through Washington and Rensselaer counties into Columbia. These strata have been greatly affected by folding and faulting, which, together with the considerable variation in the lithologic char-

acter of the rocks, frequently cause a marked difference in depth to water horizons and in the character of the water within short distances. There are springs of large flow in this region, and the supply of many of them, which appears to come from Quaternary sands and clays, is probably largely derived from the underlying strata. At Cambridge and Shushan, in Washington County, springs of very large flow are reported. At other localities springs are utilized to fill ice ponds and also furnish water power for small feed and sawmills. Most of the wells in the area are less than 100 feet deep. Their waters, except those in the limestone lenses, are soft. In the town of Cambridge, Washington County, a well drilled to a depth of 39 feet furnishes 150 to 200 gallons an hour and may be considered an average well of the region.

The Cambrian sandstone (commonly known as the Potsdam sandstone) occurs on the northern side of the Adirondacks and also in detached areas, too small to be shown on the map, on the southeastern and southern flanks. It is usually a compact sandstone varying in color from light gray to buff and sometimes reddish-brown. No records of deep wells in these sandstones have been obtained. Dug wells 20 to 50 feet deep furnish a sufficient supply for domestic purposes. Small springs are very abundant, but none of very much economic importance are known.

Ordovician.—The strata which are called Ordovician consist of a great thickness of limestone and shales, often intensely folded and highly metamorphosed. They form the surface rocks of the Mohawk River Valley, extending in a northwesterly direction from Albany to Lake Ontario along the southeastern, southern, and southwestern sides of the Adirondack area. They also occupy the greater part of the region east of Hudson River south of Lake Champlain, and south of Kingston they extend in a southwesterly direction beyond the New Jersey line. They also occur in a narrow strip along the St. Lawrence. Within these areas many springs of considerable economic importance, including a large number of mineral springs, come to the surface. They are particularly abundant in the valley of the Mohawk, and in a number of localities furnish water power and in others supply creameries, railroad tanks, etc. The celebrated mineral waters of Saratoga Springs and vicinity are found in fractured zones of the Trenton limestone, where they occur in a narrow belt extending for several miles in a northeast-southwest direction. The shale strata form the greater part of this system and afford the larger part of the water supply.

Massena Springs, in St. Lawrence County, and Lebanon Springs, in Columbia County, are old, well-known mineral spring resorts, the latter being the only thermal water in the State.

In some areas, as in southwestern Montgomery, in Albany, Colum-

78°
44°
42°
ONTARIO
LAKE ONTARIO
NIAGARA
ORLEANS
MONROE
WAYNE
Buffalo
GENESEE
ONTARIO
SENECA
YATES
LIVINGSTON
ERIE
WYOMING
LAKE ERIE
SCHUYLER
TOMPKINS
CHAUTAUQUA
CATTARAUGUS
ALLEGANY
STEUBEN
CHEMUNG
PENNSYLVA
MAP
OF
NEW YORK
SHOWING
GEOLOGIC FORMATIONS AND SPRING LOCALI
1904
Scale
20 0 20 40 60 80
LEGEND
TRIASSIC
Sandstone, diabase
DEVONIAN
Limestones, shales, sandstones
SILURIAN
Sandstones, limestones, shales
ORDOVICIAN
Limestones, shales
CAMBRIAN
Sandstones, shales
78°

bia, and other counties, wells yield from 50 to 200 gallons per minute, the water being obtained in the shales at depths of 100 to 500 feet. In some of the wells the water is hard, in others it is soft, and in many it contains considerable gas. These artesian areas are determined by varying local conditions of structure and rock composition. Wells that require pumping are very abundant, and the depth to water in the solid rocks varies with the thickness of the glacial sands and gravels which cover a large part of the Ordovician strata. The water of such wells is usually abundant, but it is frequently impregnated with iron, sulphur, and gas, which in some instances renders it unfit for drinking.

Silurian.—The Silurian rocks outcrop in a narrow band from the New Jersey line northeastward to Kingston and northward to a point opposite Albany, where the belt bends to the northwest and occupies much of the Ontario province. The sandstones that form the lower part of the system extend along the southern shore of Lake Ontario and on its eastern shore spread out over a broad area north of Oneida Lake. As the greater part of this area is covered with glacial deposits, the springs may derive their waters wholly from these beds. Several important mineral springs are found in this region, notably those of Oswego, from which water has been sold since 1870. The wells that penetrate the sandstones range in depth from 50 to 125 feet, and furnish large supplies of water, which is usually hard.

South of these sandstones is an area of limestone, in which springs of hard water are fairly abundant. No important mineral springs occur in it. In Orleans, Monroe, and Wayne counties wells drilled to depths ranging from 75 to 125 feet obtain supplies amounting in some cases to 150 gallons per hour. This limestone area narrows eastward and disappears south of Utica.

The highest rocks of this system are generally shales, and extend from Niagara River eastward in a belt parallel to the limestones and sandstones. Nearly all the waters from these shales contain mineral matter in varying amounts, and many of them are used for medicinal purposes. The water of Oak Orchard Springs, in Genesee County, is remarkable for its content of free sulphuric acid, which is a rare constituent of mineral water. In Oneida County there are a large number of mineral springs and wells near Clinton, Franklin Springs, Kirkland, and Booneville, from which water is bottled and sold. These waters come from near the junction of the sandstones and shales. One of the deep wells in this county is at Deansboro. This is 300 feet in depth and the water rises within 20 feet of the surface and is used for cooling milk. In Niagara County near Lockport a well 115 feet deep penetrated the shales and the water flows during the winter months. Near Henrietta, Monroe County, is a flowing well 65 feet in depth, which is said to afford a large supply of water.

The southern limit of the Silurian is marked by a narrow band of sandstone extending from Genesee County eastward, and along or near the line of contact there are many springs. Among these are mineral springs near Williamsville, Honeoye Falls, Clifton Springs, Chittenango Springs, and Sharon Springs.

Devonian.—Rocks of this system cover practically all the Allegheny Plateaus and Catskill provinces. It contains two prominent narrow limestone bands and a great thickness of shales and sandstones. The entire thickness of the series has been estimated at about 3,400 feet. The Silurian sandstone, just described, is succeeded to the south by a prominent limestone, which is followed farther south by a series of shales. Along the contact of this limestone and shale several important mineral springs occur. Prominent resorts and sanitariums are located at Avon, Richfield Springs, and Cherry Valley. Still farther south are springs at or near Penn Yan, Dryden, Watkins, Slaterville, and Spencer, their waters being derived from the upper portion of the Devonian sandstones and shales.

In the central and northern portions of the Devonian area comparatively few flowing wells have been reported. In Chautauqua, Cattaraugus, and Allegany counties most of the wells in rock, 100 to 500 feet deep, flow and furnish up to 1,000 gallons an hour. They are principally used for domestic purposes, creameries, oil-pumping machinery, and various manufacturing establishments. Some of them are mineralized and are considered beneficial in treating various diseases. In the southern tier of counties east of Allegany County the number of flowing wells decreases, but large supplies of water are obtained by pumping. An appreciable amount of iron and sulphur is found in the waters of many of the wells throughout the Devonian area.

Triassic.—The rocks of this system are reddish sandstone and diabase and outcrop in Rockland County. Water comes to the surface along the line of contact of these rocks in springs and seeps. At West Nyack and Bardonia the flows are estimated at 100 gallons an hour. At Nanuet and Orangeburg are other important springs. Fair supplies of water are obtained at Monsey, Spring Valley, and Orangeburg, at depths ranging from 40 to 180 feet. Most of the wells in the diabase or trap rock are shallow and the supply materially diminishes in dry seasons. In the sandstone the supply is more abundant and permanent and the water is usually soft.

Cretaceous.—The Cretaceous beds underlie the Quaternary drift at no great distance from the surface throughout the larger part of central and western Long Island and outcrop at a number of points along the north shore, and, more rarely, in the hills of the interior. Flowing wells of excellent water have been obtained at depths ranging from 100 to 700 feet below sea level.

Quaternary.—The Quaternary deposits of gravel, sand, and clay are, for the most part, of glacial origin and cover the hard rocks to a great extent. Their thickness in places amounts to 300 feet or more. Water permeates these unconsolidated materials very readily, and it is probable that the amount of well and spring water obtained from these deposits equals or even exceeds that derived from all other strata in the State. Springs are very abundant and some of them have large flows, which are utilized in many ways. Where not locally contaminated they furnish water of excellent quality, which is frequently used to supply village and town waterworks. Flowing wells are very abundant, especially in the southern part of the State, and yield from 50 to 600 gallons an hour. Thousands of dug and driven wells throughout the State derive their supplies from the Quaternary beds.

The largest supplies from the Quaternary deposits are obtained from the outwash plains and other deposits of Long Island. These plains consist largely of sand or fine gravel and are saturated with water below a moderate depth. Many towns and cities, including Brooklyn, obtain the whole or part of their supplies from shallow wells or springs that issue from the sands. Springs abound along both the north and south shores, and are found to a lesser extent in the moraine in the interior. Water from several of them is placed on the market.

PRODUCTION OF MINERAL WATERS.

If it were possible to estimate the amount and value of the water supply it would certainly rank as one of the most important of nature's products. During the past twenty years statistics have been obtained to show the amount and value of mineral waters produced and sold in the United States. For the year 1902, in New York State, 6,609,176 gallons were sold, valued at $1,299,037.[a] The bottling and shipping of water for drinking purposes in large cities and towns has become a considerable industry in many favorably situated localities. It is increasing very rapidly, but no statistics of amount or value are available.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

Commercial springs of New York.

County.	Town.	Owner.	Volume.	Character.	Use.
Allegany	Ceres	Ceres Mineral Spring Co.	Large flow	Mineral water	Medicinal.
Do	Whitesville	Whitesville Water Co	24 gallons per minute	Soft	Public supply.
Broome	Binghamton	F. D. Holcomb		Mineral water	Medicinal.
Do	Sanitaria Springs	S. A. Kilmer		do	Do.
Do	Vallonia Springs	James C. Sands	Large flow	do	Do.
Cattaraugus	Orlando	C. H. Bower		Soft	Power.
Do	West	E. E. Warn	1-inch pipe	Hard	Public supply.
Cayuga	Cayuga	Lucius Baldwin	Small flow	Mineral	Medicinal and table.
Do	Moravia		Very large	Soft	Public supply.
Do	Union Springs		do		Power.
Chemung	Breesport			Mineral	Medicinal.
Do	Chemung	Chemung Spring Water Co.	50 gallons per minute	Soft	Table water.
Chenango	Afton	Afton Waterworks	Large		Public supply.
Do	Bonney	S. Humphrey	½-inch pipe	Soft	Creamery.
Do	Oxford	Oxford Village	50 gallons per minute	do	Public supply.
Do	Smithville Flats		1-inch pipe	Slightly hard	Factory.
Columbia	Greendale	Brewer & Son	1½ gallons per minute	Soft	Table water.
Do	Lebanon	Columbia Hall Co	490 gallons per minute	Mineral	Medicinal.
Do	Pulvers	Charles Jacobia	Large flow	Soft	Table water.
Do	Stottsville	E. W. Cohen	do	Mineral	Medicinal.
Dutchess	Poughkeepsie	Mrs. E. J. Haynes	6-inch pipe	do	Do.
Erie	Williamsville	Ayers's estate	1 gallon per minute	do	Do.

Fulton	Johnstown	E. Frederick	8-inch pipe	Soft	Power.
Do	Perth	S. C. Hathaway	Large	do	Public supply.
Genesee	Batavia	Seven Spring Water Co.	3,700 gallons per minute	do	Do.
Do	Byron	Geo. Fisher	3 gallons per minute	Mineral	Medicinal.
Do	Byron Center	H. C. Norton	6-inch pipe	Hard	Cheese factory.
Do	Stafford	G. W. Scott	Very large	do	Fish ponds.
Greene	Grapeville	C. R. Palmer	do	Soft	Power.
Do	South Cairo	Geo. Duncan	50 gallons per minute	do	Public supply.
Herkimer	Fairfield	John McEvoy	Large	do	Do.
Do	Little Falls	L. A. La Rue	60 gallons per minute	do	Do.
Livingston	Avon	W. P. Wolfe	Small flow	Mineral	Medicinal.
Monroe	Fairport	W. A. Parce		do	Do.
Do	Parma			do	Do.
Oneida	Booneville	Booneville Mineral Spring Co.	4 gallons per minute	Soft	Medicinal, table.
Do	Cassville		Very large	Hard	Power.
Do	Franklin Springs	F. H. Suppe	5 gallons per minute	Mineral	Medicinal, table.
Do	do	A. W. Warner	14 gallons per minute	do	Do.
Do	Marcy	G. R. Wright	2-inch pipe	Soft	Manufacturing purpose.
Do	Verona	E. A. Groves	2 gallons per minute	Mineral	Medicinal, table.
Do	do	G. N. Lehr	do	do	Do.
Onondaga	Fayetteville	Fayetteville	Large	Hard	Public supply.
Do	Manlius	Village of Manlius	do	do	Do.
Ontario	Clifton Springs	Sanitarium	Very large	Mineral	Medicinal.
Do	Phelps	E. F. Marsh	Large	Hard	Public supply.

Commercial springs of New York—Continued.

County.	Town.	Owner.	Volume.	Character.	Use.
Orange	Port Jervis	L. L. Blackman			
Oswego	Fulton	Great Bear Water Co	250 gallons per minute	Slightly mineral	Table.
Do	Oswego	Nelson Morrow			
Otsego	Cherry Valley	L. W. Thompson			
Do	Richfield Springs	T. R. Proctor	Very large	Mineral	Medicinal.
Rensselaer	Hoosick Falls	Bratt's estate	200 gallons per minute		Power.
Rockland	Nanuet	W. Davidson		Mineral	Medicinal.
St. Lawrence	Massena		Large	do	Do.
Saratoga[a]	Ballston				
Do	Gurnspring	C. E. Roods	1 gallon per minute	Mineral	Do.
Do.[a]	Saratoga				
Do	Wayville	T. C. Luther	2-inch pipe	Mineral	Do.
Schoharie	Sharon Springs	J. H. Gardner & Son	200 gallons per minute	do	Do.
Schuyler	Montour Falls	C. D. Clauson	1½ gallons per minute	do	Do.
Do	Watkins	Glen Springs Co		do	Do.
Seneca	Canoga	S. T. Allen	Large	Hard	Power.
Steuben	Canisteo	Waterworks Co	100 gallons per minute	Slightly hard	Public supply.
Sullivan	Willowemoc	Elias Depuy	8-inch pipe	Soft	Manufacturing.
Do	Livingston Manor	Charles Ellis		do	Creamery.
Tioga	Apalachin	M. S. Olmstead	12 gallons per minute	Mineral	Medicinal.
Do	Halsey Valley	Ira Hoyt	Very large	Soft	Power.
Tompkins	Dryden	S. S. Nivison	Large	Mineral	Medicinal.
Do	Slaterville		6 gallons per minute	do	Do.

Ulster	Clintondale	S. P. Thorn	50 gallons per minute	do	Medicinal, table.
Do	Ellenville	F. S. Benedict	100 gallons per minute	Soft	Table water.
Warren	Adirondack	C. H. Van Brunt	120 gallons per minute	do	Do.
Do	Bolton Landing	Green Island Improvement Co.	Very large	Slightly hard	Public supply.
Do	Chestertown	F. Velter	6 gallons per minute	Soft	Do.
Washington	Cambridge	Cambridge Waterworks Co.	2,000 gallons per minute	do	Do.
Do	Fort Edward	Brewing Co	Large	Mineral	Medicinal.
Do	Whitehall		Small	do	Do.
Westchester	Bronxville	W. V. Lawrence	Large	Soft	Table water.
Wyoming	Arcade	Waterworks Co	2,000 gallons per minute	Slightly hard	Public supply.
Do	Bliss	Chas. Walton	Very large	Soft	Do.
Do	Eagle	J. G. Mitchell	do	Hard	Power.
Do	Pearl Creek	W. A. Hawley	17 gallons per minute	Soft	Milk station.
Yates	Branchport		do	Mineral	Medicinal.

[a] Mineral waters are now almost wholly obtained from deep wells.

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Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, 1902, pp. 15–19.

New York [well and spring records], by F. B. Weeks: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, 1904, pp. 169–206.

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Water resources of the Taconic quadrangle, New York, Massachusetts, and Vermont, by F. B. Taylor: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1905, pp. 130–133.

Water resources of the Watkins Glen quadrangle, New York, by R. S. Tarr: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, pp. 134–140.

NEW JERSEY.

By G. N. Knapp.

TOPOGRAPHIC PROVINCES.

New Jersey has been divided into four provinces, or zones, on the basis of its physiographic features. These provinces are indicated on

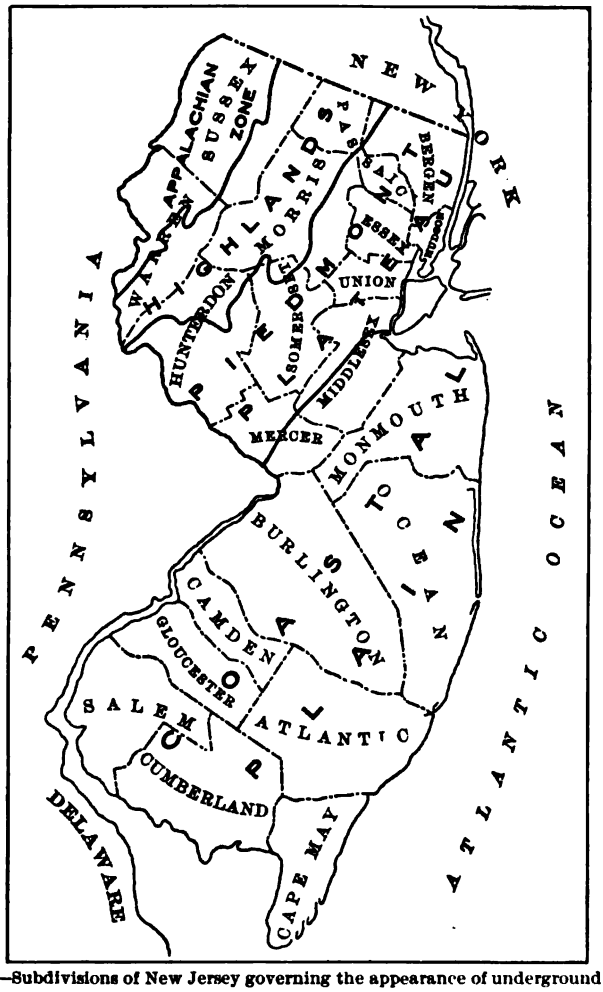


Fig. 18.—Subdivisions of New Jersey governing the appearance of underground water.

the accompanying sketch map (fig. 18) and are designated (1) the Appalachian, (2) the Crystalline Highlands, (3) the Piedmont, and (4) the

Coastal Plain.[a] The surface features of these several provinces, by reason of which they differ the one from the other, are in large measure simply the outward manifestations of geologic characters, structural and lithologic, which are inherent in the terranes of the different provinces and which have found topographic expression through subaerial and stream degradation.

As might be expected the underground or deep waters of the State sustain relations that differ in the different provinces and that are more or less characteristic of them. Rocks so different in structure and lithologic character as to give rise to topographic features that are as distinct and characteristic as are those of the several provinces might be expected to profoundly affect the disposition of underground water. This is, in fact, found to be true, and this subdivision of the State is regarded as the one best adapted to a general discussion of the deep waters.

GEOLOGY AND WATER SUPPLY.

APPALACHIAN PROVINCE.

The Appalachian province, or zone, is the northern extension in New Jersey of the great Appalachian mountain system. It is essentially coincident with the great Kittatinny Valley and Kittatinny Mountain.

The rocks consist of limestone, slates, conglomerates, sandstones, and quartzites, strongly infolded in anticlines and synclines whose axes run northeast and southwest. These primary folds have been more or less faulted and modified by dikes and other late intrusions. The whole series has been profoundly eroded, plains of degradation have been developed, truncating the old folds, and later broad, deep valleys have been developed parallel to the main axes of the folds. In these broad valleys the softer beds, such as limestones and shales, stand at angles that range from vertical to horizontal and dip in various directions. The ridges or mountains that inclose these valleys consist of the harder rocks, viz: Conglomerates, quartzites, slates, and sandstones, which rise more or less abruptly to heights of 1,000 or 1,500 feet above the valleys. The beds themselves stand at various angles, commonly approaching verticality.

The various beds of the Kittatinny Valley have in large measure lost through metamorphism whatever porosity they may once have had. The sandstones have become quartzites, more or less dense; the conglomerates have suffered a like modification, reducing their porosity to a minimum, and the other rocks have undergone similar changes, tending to increase their density. The rocks have, however, been fractured at various times, so that joints occur more or less abundantly

[a] New Jersey Geol. Survey Final Report, Vol. IV, Physical Geography, 1895.

throughout the beds, admitting water to unknown depths. In the limestones solution has developed cavities and more or less definite underground courses.

The rocks then of the Appalachian province are relatively impervious and do not carry a large volume of water. The water that penetrates deeply does so by virtue of secondary structures and other modifications that do not stand in close relation to the primary structure.

Therefore a knowledge of the structure, which is regular enough to be determined with considerable definiteness, is not of so much service in locating successful wells as might be expected. The water seems capricious in its occurrence. The data available, however, show but few deep wells in this province—too few to be made the basis of final conclusions, so that the great Kittatinny Valley has yet to be thoroughly tested for its available deep water supply.

CRYSTALLINE HIGHLANDS PROVINCE.

The Crystalline Highlands, as the name suggests, consists more largely of crystalline rocks—granites, schists, and gneisses. The great structural lines of the province run northeast and southwest, like those of the Appalachian zone, but this region has been subject to more profound metamorphism and the beds have been repeatedly broken and faulted at widely separate time intervals. Intrusive rocks have been injected as dikes and masses at different times, secondary structures have very generally destroyed or replaced the original ones, and along with this have gone replacement and interchange of the mineral constituents of the rocks.

In the Crystalline Highlands, therefore, the structure is too complex and too indefinite to aid one in a practical way in predicting the result of wells, and the terranes contain no well-defined porous beds that in a true sense can be called water bearing in contradistinction to others. The rocks, however, as a whole, are more generally permeated by water than in the Appalachian zone, so that wells put down indiscriminately give a larger percentage of satisfactory wells in the former than in the latter region. We know from the numerous iron mines scattered through the Highland region that the permeation of these old crystallines by water, while very general, is by no means uniform; for some mines encounter large volumes of water, greatly to their detriment, whereas others are comparatively dry. The relation, if any, that exists between the local rock structure or the depth of the mine and the volume of water encountered is not apparent.

In the Highland province there are some areas that form notable exceptions to the structure above outlined; such, for instance, as the Green Pond mountain belt, where the rocks and structure are analogous to the infolding of the Appalachian zone. In these exceptional areas the deep waters behave much as they do in the Kittatinny region.

The numerous streams, as yet not polluted, afford an abundance of excellent water. This, together with the cost of drilling in such hard rock, i. e., $5 to $10 a foot, has heretofore limited the number of deep wells.

This province, however, is being invaded by suburban homes and country residences, and we may expect that in the near future more deep wells will be bored.

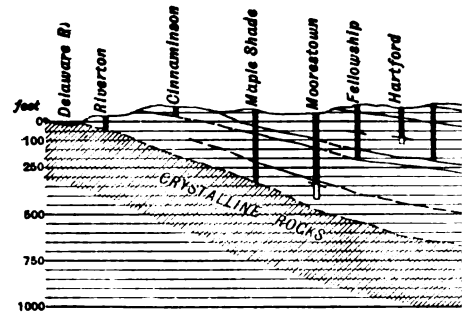
PIEDMONT PROVINCE.

The Piedmont province is essentially the area of the Newark system. The Newark consists of three series of beds which, from base upward, are the Stockton, the Lockatong, and the Brunswick. The Stockton consists of light-colored sandstones and conglomerates, more or less arkose, interbedded with a few red shales. It is the most permeable series of the Newark system. The Lockatong consists chiefly of flagstones and argillites, and is relatively impervious. The Brunswick series consists chiefly of shales, but includes also many beds of sandstone. It is less permeable than the Stockton.

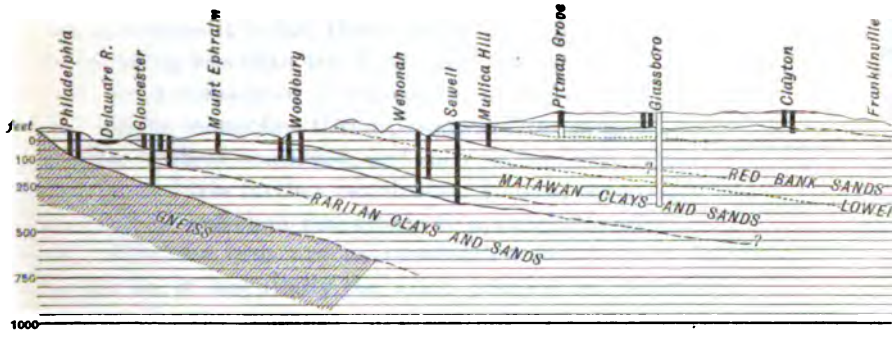
The Newark system is traversed by a number of irregular faults whose throw is nearly sufficient to repeat the entire system at each successive fault. The prevailing dip of the beds is west and northwest, but more or less local warping and tilting that accompanied the faulting gave the beds many local variations in dip and strike. The structure of the Newark is further complicated by an irregular system of volcanic intrusive sheets and trap dikes that cut across the bedding at various angles.

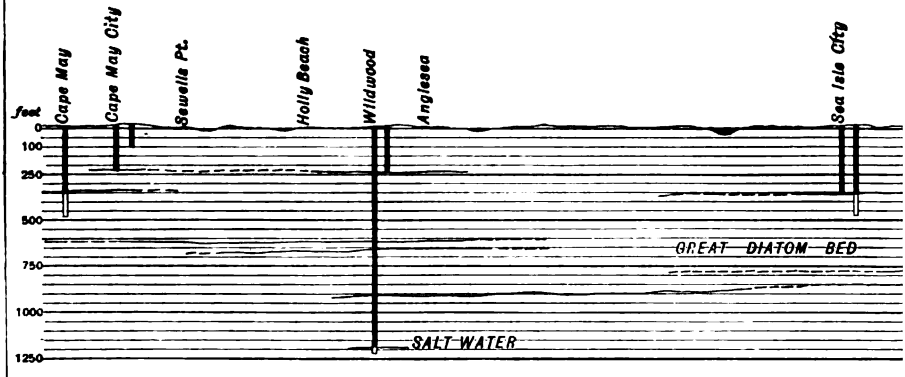
The faulting of the Newark in a way to repeat the succession is a slight advantage in some situations, since it makes the Stockton beds more readily available for artesian water at some localities than they otherwise would be, but in other situations the faults cut off the supply entirely, so that the advantage in one locality is in large measure offset by the disadvantage in the other. One familiar with the complex structure of the Newark can forecast the chances of obtaining artesian water at given points in the Piedmont province; but it would be difficult for one unfamiliar with the structure to make such forecasts.

The Newark system is thoroughly cut up by two or more systems of deeply penetrating joints, whose planes are nearly vertical and intersect one another at various angles. It is thought that the copious wells in the Newark draw their supply from these joints and fissures more largely than from the water that penetrates along the true bedding planes. Nearly one half of the northern end of the Piedmont province is, however, mantled by glacial drift which conceals many of the minor details of the Newark structure. This not infre-



SECTION 3: PHILADELPHIA TO MOUT





quently entirely precludes the possibility of calculating closely the chances of artesian water at certain points.

Of the three provinces thus far considered, the Piedmont carries vastly more deep water than either of the others. Moreover, the water is found in rocks that are drilled with comparative ease, and the chances of obtaining it can be foretold with much definiteness. Furthermore, the Piedmont is, by virtue of its geographic position, the most important of the three, since it includes what is and what always will be the most densely populated part of the State, in which the water supply will always be a paramount question.

COASTAL PLAIN PROVINCE.

The Coastal Plain differs from the three northern provinces in nearly every essential feature. First, it includes an area greater than the combined area of the other three provinces; second, as compared with the other provinces it is flat, there being no mountains and the maximum relief being less than 400 feet; third, its structure is of the simplest sort, for it consists of a succession of beds lying one upon the other in a simple monocline that dips seaward, the uppermost or youngest bed lying farthest southeast, and each successively older and lower bed reaching a little farther northwest; fourth, there have been no faults or folds of sufficient magnitude to appreciably affect the general structure; fifth, the beds are unconsolidated sands, clays, marls, and gravels, and lie in essentially the same position in which they were deposited; sixth, the terranes have not suffered any metamorphism that has appreciably affected their permeability to water.

The Coastal Plain province falls into two great geologic divisions or subprovinces, viz, the Cretaceous and the Tertiary. The Cretaceous occupies a relatively narrow belt that extends across the State, while the Tertiary covers the remainder of the province.

The Cretaceous has three major divisions, which, reckoned from base upward, are the Raritan, the Clay Marl series, and the Marl series. The Clay Marl series corresponds approximately but not exactly to the "Matawan" of the later nomenclature, while the Marl series includes approximately but not exactly the Monmouth, Rancocas, and Manasquan of later nomenclature.

The Raritan, though carrying important water beds at different stratigraphic horizons, does not admit of subdivision. The Clay Marl series, on the other hand, is readily subdivided into five beds, the lower two of which are impervious marl and clay and serve as a cover to the Raritan water-bearing sands. The stratum next above is a sand bed, which is 100 feet thick to the northeast, where it is an important water horizon; toward the southwest it pinches out entirely and disappears along the strike. Above this is an impervious marl and clay.

Next comes a sand bed 100 feet thick to the southwest, where it is an important water horizon. To the northeast it becomes less important, partly by reason of its decrease in thickness in that direction and partly by a decrease in permeability.

The Marl series, like the Clay Marl series, is readily subdivided into five beds, the lower of which corresponds to the Lower Marl, approximately the "Navesink." Above this is the Red sand (Redbank). Toward the northeast it is a sand bed 100 feet thick, but toward the southwest it pinches out and disappears along the strike. Next above is the lower portion of the old Middle Marl bed—the marl proper. It constitutes a part but not all of the Sewell. Still higher is the Lime and "Yellow" sand; the upper part of the old Middle Marl bed, including the "Vincenttown" and more. This is an important water horizon all across the State. The top bed is the Upper Marl, a part of which is Eocene. It is the impervious cover to the preceding.

The second subprovince of the Coastal Plain, the Tertiary, is divided into two formations, the Kirkwood (Miocene), and the Cohansey (Pliocene?). The lower bed is the Kirkwood. It carries water-bearing sands at several different stratigraphic horizons. It is an important source of water at Atlantic City and at points farther south along the beach. Next higher is the Cohansey formation. It carries water at several different stratigraphic horizons and rivals the Kirkwood as a source of artesian water along the beach.

The structure of the Coastal Plain is extremely simple. The outcrop of the beds is known in great detail. Their dip is known, or is readily determinable, and the altitudes of the various beds can be closely estimated at all points. Still the predicting of artesian water at any given point is not a simple mathematical proposition. Two chief difficulties are experienced in predicting the results of wells: First, the thickening of the beds down the dip, seaward, has not been worked out in detail for individual beds; second, the permeability of the beds is a variable factor, whose exact value is yet to be determined.

In the following table the results of borings at a large number of localities on the Coastal Plain are presented:

Summary of well statistics in the more important of the Coastal Plain localities.

[Compiled from tables of N. H. Darton.[a]]

Locality.	Range of depth.		Range of capacity per minute.		Geologic horizons of water.
	From—	To—	From—	To—	
	Feet.	*Feet.*	*Gallons.*	*Gallons.*	
Asbury Park	383	1,330	20	500	Lower marl, Matawan, Raritan.
Atlantic City	118	1,398	0	400	"Diatom bed," Cretaceous, Chesapeake.
Atlantic Highlands	108	480	80	250	Matawan, Raritan.
Barnegat Landing	.....	120	.....	.....	
Bayhead	.....	710	.....	.....	Lower marl.

[a] Bull. U. S. Geol. Survey, No. 138, pp. 42–48.

Summary of well statistics in the more important of the Coastal Plain localities—Cont'd.

Locality.	Range of depth.		Range of capacity per minute.		Geologic horizons of water.
	From—	To—	From—	To—	
	Feet.	*Feet.*	*Gallons.*	*Gallons.*	
Bayside	.....	190	0	.....	Unknown.
Beach Haven	430	575	10	125	Bed C, Atlantic City; bed E, Atlantic City.
Berkeley Arms	.....	470	.....	60	960 feet at Atlantic City(?).
Bordentown	119	195	.....	Many.	Raritan, basal Raritan.
Bridgeton	.....	90	0	.....	Post-Chesapeake.
Brigantine	.....	798	.....	100	800 feet at Atlantic City.
Burlington	135	253	0	25; plenty.	Raritan.
Camden	112	152	16	150	Basal Raritan.
Cape May City	.....	224	.....	75	Upper Chesapeake. Unknown.
Cape May Point	.....	360	.....	Fair supply.	Upper Chesapeake.
Clayton (6 wells)	.....	105	.....	Each, 150	Post-Chesapeake(?).
Collingswood	.....	196	.....	Fair supply.	Raritan.
Columbus	156	356	.....	10; fair supply.	Raritan, basal Matawan.
Crab Island	.....	520	.....	Satisfactory.	*b*
Englishtown	.....	210	0	.....	Matawan.
Fellowship	.....	131	.....	Many.	Do.
Fifields	.....	397	0	.....	Chesapeake.
Freehold	172	322	25?	250; unsatisfactory.	Lower marl, Matawan.
Glassboro	.....	511	0	100	Post-Chesapeake, Matawan.
Gloucester	102	270	100	650	Basal Raritan, basal Matawan, Raritan.
Great Sedge Island	.....	320	.....	100	
Greenwich	.....	690	0	.....	Lower marl.
Harrisia	.....	375	.....	.....	
Harrisonville	.....	122	.....	Plenty.	Middle marl.
Hartford	.....	187	0	.....	Matawan.
Harvey Cedars	240	500	.....	100	
Hightstown	201	500	12	70	Matawan, Raritan, basal Raritan
Holmdel	.....	601	0	.....	Raritan.
Jamesburg	.....	481	.....	52	Do.
Keyport	.....	242	.....	12	Do.
Lake Como	.....	535	.....	.....	Lower marl.
Lakewood	.....	475	.....	.....	Do.
Longport	.....	803	.....	180	Bed G, Atlantic City.
Lucaston	.....	110	.....	.....	Middle marl.
Mantoloking	175	922	.....	.....	Bed C, Atlantic City, lower marl, Matawan.
Maple Shade	.....	375	.....	.....	Basal Raritan.
Marlton	102	365	0	20; fair to plenty.	Redbank, lower marl(?), Matawan.
Matawan	.....	100	.....	.....	Matawan.
Mays Landing	100	176	7	25	428 feet, Atlantic City(?), bed C, Atlantic City(?).
Mechesatankin Creek	.....	158	.....	Unsatisfactory.	
Medford	126	183	.....	Plenty; satisfactory; 200.	Redbank, lower marl.

Summary of well statistics in the more important of the Coastal Plain localities—Cont'd.

Locality.	Range of depth.		Range of capacity per minute.		Geologic horizons of water.
	From—	To—	From—	To—	
	Feet.	*Feet.*	*Gallons.*	*Gallons.*	
Millville	150	160		Satisfactory.	
Monmouth Beach		380			Matawan.
Monmouth Park		385		75	Do.
Moorestown		150			Basal Matawan.
Mount Ephraim		130		Satisfactory.	Basal Matawan(?).
Mount Holly		675			Raritan.
Mullica Hill		102			Redbank.
Ocean Beach	480	485	25	50	Lower marl.
Ocean City	760	800		140	Chesapeake diatom bed.
Ocean Grove	420	1,134		40	Lower marl, Matawan.
Pavonia	112	174		275	Raritan, basal Raritan, crystalline rock.
Perth Amboy	130	470	0		Basal Raritan, 70–470 feet in gneiss.
Pleasant Mills	158	201		500; unsatisfactory.	658 feet at Ocean City(?), Chesapeake.
Port Monmouth		+100		Few.	Matawan.
Point Pleasant		806		45	Do.
Port Norris		200		1	
Port Republic		151			428 feet, Atlantic City(?).
Quinton	248	275		55	Redbank.
Rancocas		124			Basal Matawan.
Redbank		230		165	Lower marl, Matawan.
Riverside (8 wells)		200	18	Each; 40	Raritan(?).
Rumsen Neck		210		60	Matawan.
Runyon Station		160	0		
Sayreville		976		Many.	Basal Raritan, 80,976 feet in gneiss.
Sea Girt		755		50	Matawan.
Seabright	125	258	55	210	Lower marl, Matawan.
Sea Island City		380		30	Above diatom bed.
Seven Islands	408	535	60	70	Bed E, Atlantic City; bed C, Atlantic City(?).
Sewell		420		25	Basal Matawan.
Shrewsbury		200	0		Lower marl.
South Amboy		105			Basal Raritan.
South Beach Haven		425		10?	Bed C, Atlantic City.
Spring Lake		465		Many.	Lower marl.
Stockton	116	130		875	Basal Raritan, Raritan.
Straight Creek		100		Many.	
Trenton		160		Many; 200	Post-Chesapeake(?). Basal Raritan.
Vineland		205		20	Post-Chesapeake.
Waretown		280		20	Bed E, Atlantic City.
Wenonah	196	341			Basal Matawan, Matawan.
Weymouth		106	52	70	Bed C, Atlantic City(?); 650 feet at Atlantic City(?); bed C Atlantic City(?).
Wildwood	215	931	10	300; unsatisfactory.	Upper Chesapeake, 240 feet below great diatom bed; in great diatom bed.
Winslow	135	145	20	40	Chesapeake, 960 feet at Atlantic City(?).
Woodbury	113	163		8	Matawan, basal Matawan.
Woodstown	139	776		360	Basal Matawan, Redbank, Raritan.

SUMMARY OF WATER RESOURCES.

The accompanying table brings into prominence many important relations and suggests many more.

Distribution of wells by provinces.

	Appalachian.	Crystalline Highlands.	Piedmont.	Coastal Plain.
Area in square miles	547.0	945.0	1,463.0	5,099.0
Approximate population	24,201.0	76,029.0	1,222,586.0	495,072.0
Average number of people per square mile	44.2	80.4	836.3	97.7
Maximum density of population per square mile per township	1,590.0	8,475.0	22,560.0	14,492.0
Minimum density of population per square mile per township	23.0	26.0	37.0	6.0
Records of wells	23.0	31.0	547.0	998.0
Average number of square miles to each well	24.0	30.0	26.0	5.0

It will be noticed that of the 1,600 wells catalogued, nearly 1,000 are in the Coastal Plain province. These range in depth from 50 to 2,300 feet and probably 90 per cent of them are of the true artesian type—that is, they draw their water from beds whose catchment area is remote, and the water in the wells rises nearly or quite to the surface, and frequently above the surface. Of the 550 wells in the Piedmont Plain very few are of the true artesian type. They range in depth from 50 to 2,300 feet. Many of them yield large volumes of water and a few of them flow, but, as before suggested, they probably draw their supplies largely from the joints and the secondary structures of the rocks. Of the 50 or 60 wells in the two northern provinces, only a few are truly artesian. They are practically all simply deep reservoir-like holes into which water percolates from innumerable joints and fissures at all horizons. While the gathering ground of such waters may be remote from the wells, they belong in a different class from those of the Coastal Plain. It will be remembered that the wells here catalogued are the ones of which records have been obtained, and not the actual total number of wells in these provinces. There are undoubtedly many wells of which no records have been procured.

The Appalachian and Crystalline provinces are relatively sparsely settled. In them springs abound, and mountain streams, proverbially wholesome and as yet unpolluted, are numerous and well distributed, so that the demand for deep wells is not pressing.

DISTRIBUTION OF WELLS AND POPULATION.

The Piedmont area includes two fairly distinct subprovinces. The first, including the northeast part of the area, in the vicinity of Essex and Hudson counties, is occupied by numerous cities, large and small, many of which are manufacturing centers, while the second, in the southwest portion, in the vicinity of Somerset County, is dominantly an agricultural region. The first of these subprovinces includes about one-fifth of the area of the Piedmont province and contains about nine-tenths of its population, the remaining one-tenth of the population being scattered over the southwestern four-fifths of the province. Of the 550 wells in the Piedmont province more than 500 occur in the densely populated region in its northeastern portion and the water, for the most part, is used for manufacturing purposes.

In the Coastal Plain province the densely populated districts are distributed around its periphery, the interior being more sparsely settled. The distribution of the artesian wells stands in fairly definite relation to the density of population. Along the seashore are many thriving towns and cities whose function is almost wholly that of ministering to the service of those in quest of health, recreation, and pleasure. These communities, while not absolutely dependent on artesian wells for their water, find them the most satisfactory available source of supply, and hence a large percentage of the wells are found along the coast.

The north and northwest border of this province, which is approximately the outcrop of the Cretaceous terranes, finds its interests divided between agriculture and manufacture. Artesian wells are abundant in this region but are not so deep as those along the coast, and are accordingly less expensive. They serve both the manufacturing and the agricultural interests. In fact, the distribution of the artesian wells is determined, first, by the availability of the water; second, by the density of the population, and third, by the character of the population.

MINERAL SPRINGS.

Sixteen mineral springs in New Jersey reported sales of water in 1902, and many more are the site of pleasure resorts of more or less importance. The aggregate production for the year is given as 360,900 gallons, with a value of $41,875. The springs reporting are as follows:[a]

Alpha Spring, Springfield, Union County.
Beacon Mountain Spring, Denville, Morris County.
Beech Springs, near Woodbury, Gloucester County.
Fowler's Deep Rock Artesian Well, Allwood, Passaic County.
Hatawanna Spring, Buddlake, Morris County.
Holly Springs, Swedesboro, Gloucester County.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

Indian Kalium Spring, Gloucester, Camden County.
Indian Spring, near Rockaway, Morris County.
Kalium Springs, Collingswood, Camden County.
Oakland Vernam Spring, near Oakland, Bergen County.
Pine Lawn Spring, Hohokus, Bergen County.
Trinity Springs, Ridgefield, Bergen County.
Turtle Hill Spring, Passaic, Passaic County.
Washington Mountain Spring, Pennington, Mercer County.
Washington Rock Spring, Warrenville, Somerset County.
Watchung Spring, Plainfield, Union County.

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PENNSYLVANIA.

By M. L. Fuller.

TOPOGRAPHY.

There are three distinct topographic belts in Pennsylvania: (1) A southeastern belt, whose northern boundary starts about 10 miles southeast of Easton and passes southwestward, just south of Reading and Harrisburg, to a point a few miles west of Gettysburg; (2) a central belt, lying north and west of the first, whose northern boundary reaches from the northeastern part of the State westward and southwestward, past Williamsport, Lock Haven, and Altoona, to the southeastern portion of Somerset County; and (3) a northwestern belt which embraces the entire northern and western portions of the State. (See fig. 14.)

The eastern belt, known as the Piedmont Plateau, is in general of low elevation, and consists of a broadly rolling surface with few high hills. The central belt, constituting the Appalachian Mountains and Valley, consists of a large number of long, straight, or gently curving ridges, alternating with deep valleys, the widest of which is the Cumberland or Shenandoah. Many of these ridges rise to altitudes ranging between 1,500 and 2,500 feet. The third belt, known as the Allegheny Plateau, is a broad surface, cut throughout its extent by streams which now flow in deep and frequently canyon-like valleys. A few ridges rise above the common level of this upland, but the plateau has a general southwestward slope, and varies in altitude from about 2,000 feet in the northern portion of the State to approximately 1,200 feet in the southwestern portion.

GEOLOGY.

The geologic divisions correspond in general with those of topography; in fact, the geology has governed the character of the topography throughout the State. The southeastern topographic belt, or Piedmont Plateau, is underlain largely by crystalline rocks which have been very evenly eroded and consequently present few conspicuous topographic features. Along the northern border of this belt is a

band of soft Triassic shales and sandstones of a topography similar to that of the adjoining crystalline area. The continuity of the belt is, however, broken by a series of folded Cambrian and Silurian quartzites and limestones that extend from near Trenton westward across the Susquehanna to the southeast corner of Adams County. The cities of York and Lancaster are located in this belt, while Phœnixville, Norristown, and Trenton lie just outside its borders.

The rocks of the middle topographic belt, which is characterized by prominent ridges, consist mainly of strongly folded beds of Cambrian, Silurian, and Devonian age, but the folded rocks of the anthracite coal basin and of the Broadtop coal basin in the south-central portion of the State are of Carboniferous age.

The rocks of the remaining or plateau portion of the State are Devonian and Carboniferous, the former constituting the surface in the northern and northeastern portion of the State and the latter in its western part. The rocks of this belt are characterized in general by

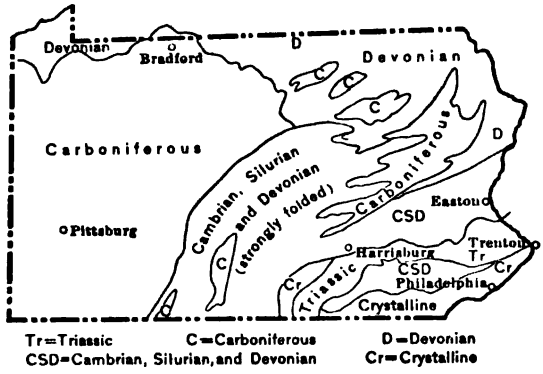

FIG. 19.—Geologic subdivisions of Pennsylvania.

very moderate folding, although the rocks of Laurel Hill and other ridges in the southwestern portion of the State show high dips. The folds generally decrease uniformly in magnitude as their distance from the Appalachian Front increases, until in the northwestern part of the State only slight and irregular undulations can be detected. It is along the crest of the anticlines that the lower Devonian rocks are brought to the surface in the northern part of the State.

SOURCES OF WATER SUPPLY.

STREAMS AND LAKES.

By far the larger number of the streams of Pennsylvania rise either in the mountainous regions of the Appalachian belt or in the highlands of the Allegheny Plateau. In general they have their sources in rugged forest-covered areas remote from habitations, and for considerable distances flow with their original purity through thinly

populated districts. Even within a few miles of some of the large cities supplies from unpolluted streams may be procured. The waters of the larger streams, however, are generally polluted and unsafe for domestic use except where they are subjected to some process of purification. There are no large natural lakes within the State, but a few small ponds are found in depressions in the drift on some of the flat mountain tops and elsewhere in its northern portion. These ponds are seldom of any value as a source of water supply.

WELLS.

The drift.—The glacial drift in Pennsylvania is confined to the northern half of the State. The glacial boundary enters from the east at a point not far from Easton and passes northwestward to the New York line not far from Bradford. Here it leaves the State for a few miles, but soon turns south again, reenters the State and passes southwestward to a point a few miles north of Ohio River at the western border of the State.

In the area south of this line the loose materials at the surface, except in the river and stream valleys, consist of fragments of rock which have been broken up to form a stony soil under the action of the weather. North of the glacial boundary this residual soil has been reworked by glacial action and mixed with foreign material brought down from the north, the whole being left as a heterogeneous stony mantle, known as till, covering the surface. In addition to the till many deposits of gravel or sand were laid down in the valleys by streams flowing from the glacier.

The till usually contains a considerable percentage of clay and is not usually a satisfactory source of water. Nevertheless it furnishes small supplies to wells at many points throughout the northern portion of the State. The water follows rather definite courses through the material and its occurrence can not always be predicted. Its amount is almost always small, but it is of very fair quality. Springs are common, but are usually small and of little economic value.

Stream deposits.—In the stream deposits, which consist largely of gravel and sand, great quantities of water are stored, especially in the larger river valleys. The great absorptive power of these materials is strikingly shown by their rapid absorption of the mountain streams which emerge upon them. Wells driven but a few feet into such deposits often find abundant supplies. Their waters are almost always of excellent quality if taken at sufficient depth to be out of the zone of pollution from the surface.

Crystalline rocks.—The crystalline rocks consist of gneisses and similar granitic rocks. In general they carry but little water, for their porosity is small and they are not characterized by bedding planes that

offer easy passages for water. These rocks are, however, cut by more or less vertical joints which admit considerable quantities of water under favorable conditions. Wells drilled in the crystalline rocks, especially in Philadelphia and vicinity, have frequently obtained moderate to good supplies at depths of from 100 to 300 feet. As a rule, wells that fail to obtain a supply within 300 feet of the surface will not afford much water at greater depths. Springs are relatively few in number and small in size, and are seldom used except in the vicinity of the large cities, where they furnish considerable quantities of water for table use.

Triassic rocks.—The Triassic rocks, the extent of which has already been indicated, consist of shales and soft sandstones, frequently stained red by iron oxide. The sandier beds contain a large quantity of water, a cubic foot sometimes holding a quart or more. Many wells have been drilled into these rocks in the towns scattered along their outcrop and considerable supplies have been obtained in some places. The waters, however, are liable to be strongly mineralized and in some cases it is impossible to use them in boilers. Springs occur in the Triassic rocks, but are not commonly important.

Cambrian and Silurian rocks.—The Cambrian and Silurian rocks consist of quartzites, limestones, and shales. They are characterized throughout, as has already been indicated, by strong folds, the rocks in many instances being almost on edge. The outcrops of the formations generally occur, therefore, as rather narrow, straight, or gently curving bands, although belts of considerable width are found where the folds are more open.

The true quartzites are dense, compact, and nonporous, exhibit very little jointing, and are frequently destitute of recognizable bedding planes. Under such conditions they are practically destitute of water. Some of the beds, however, especially the Medina and Oriskany sandstones, are less dense, and carry water which issues as fine large springs where the outcrops are favorable. The limestones, which include the Trenton and Lower Helderberg, are rather dense and carry water only in solution channels. For this reason the finding of water in them is uncertain, and they are, therefore, rarely a source of supply, although in some cities and towns deep wells have obtained satisfactory supplies from these rocks. There are many fine springs along the edges of the limestone areas, but in the central portion of the outcrops cisterns are mainly relied upon for water for domestic purposes.

The shales carry some water in their bedding planes and in sandy interbedded layers. Small springs are fairly common, and in the less strongly folded portions wells usually obtain moderate supplies.

Devonian rocks.—The Devonian rocks, as already indicated, occur to some extent infolded with the Cambrian and Silurian rocks, and are also brought to the surface by gentle folds in the northern portion of

the State. They consist largely of shales, although sandstones are frequently present, especially in the subdivision of the Devonian known as the Catskill. Limestones are occasionally present. Springs are numerous in the areas where the Devonian shales and limestones outcrop, but they are small as compared with the springs of the Cambrian and Silurian areas. They afford, nevertheless, pure supplies for a large number of the inhabitants in the areas in which they occur. Wells also generally obtain fair supplies. In the synclines or basins flowing water is not uncommonly obtained by the deeper wells, but, because of the abundance of spring water and of water in the drift, deep wells are not often sunk.

Carboniferous rocks.—The Carboniferous rocks consist of a thick series of sandstones, shales, limestones, and coals. The limestones are generally only a few feet thick, but some of the beds may run up to 50 or 100 feet, or even more. They are not prominent water bearers, although small supplies are almost always obtained either at their upper surfaces or from some of their bedding or joint planes.

The Carboniferous shales, like the Devonian, frequently carry water along their bedding planes and in their interbedded sandy layers, but though giving rise to a considerable number of springs and furnishing supplies for many shallow wells, they are not conspicuously water bearing.

Water is frequently found associated with the coals, but is almost always highly charged with ferrous sulphate, resulting from the decomposition of the pyrite in the coal. Sandstones are often of great thickness and are fairly open and porous. Where above drainage level they commonly carry relatively little water, but below this level they are often saturated, and drilled wells penetrating them generally obtain good supplies. Where the rocks lie a considerable distance below the surface, however, the fresh water is liable to be replaced by salt water or by oil; hence deep wells are sometimes of little value as sources of water supply. Flowing water is frequently obtained in the synclines or basins and elsewhere where the conditions are favorable, but the water will seldom rise more than a few feet above the surface, and pumping is almost universally necessary to raise it for industrial uses. In general, fresh waters in the Carboniferous and Devonian rocks are found within 500 feet of the surface. Below this point the rocks are in some places entirely destitute of water, and in others carry salt water as indicated above.

Coastal Plain deposits.—The eastern portion of Philadelphia is underlain by Coastal Plain formations, consisting of the lower beds of the Raritan-Potomac deposits. These beds are water bearers and have been tapped by a number of wells in the city.

MINERAL SPRINGS.

The waters of Pennsylvania, except those of the Triassic area, of the limestones, and those associated with coals, are usually low in mineral matter. There are, however, scattered throughout the State a number of deep-seated springs the waters of which are mineralized. Many of these mineral waters are bottled and sold commercially, and resorts of importance have been developed about others. The mineral springs are not confined to any one class of rocks, but are found in all of the types described. The following springs reported shipments in 1902:[a]

Artesia Spring, Harrison Valley, Potter County.
Bedford Chalybeate Spring, Bedford, Bedford County.
Bedford Mineral Springs, near Bedford, Bedford County.
Black Barren Mineral Spring, Pleasant Grove, Lancaster County.
Buena Vista Springs, Buena Vista, Franklin County.
Charmian Mineral Spring, Charmian, Franklin County.
Cloverdale Artesian Lithia Spring, Newville, Cumberland County.
Corry Artesian Mineral Spring, Corry, Erie County.
Cresson Springs, Cresson, Cambria County.
De Vita Mineral Springs, Cambridge Springs, Crawford County.
East Mountain Lithia Well, near Factoryville, Wyoming County.
Ephrata Mountain Crystal Spring, near Ephrata, Lancaster County.
Glen Summit Spring, Glen Summit, Luzerne County.
Gray Mineral Spring, Cambridge Springs, Crawford County.
Imperial Spring, Angelica, Berks County.
Korrylutz Well, Corry, Erie County.
Magnesia Spring, Cambridge Springs, Crawford County.
Malvern Spring, Malvern, Chester County.
Parker Mineral Spring, Gardeau, McKean County.
Pavilion Spring, South Mountain, Wernersville, Berks County.
Petticord Mineral Spring, Cambridge Springs, Crawford County.
Pulaski Natural Mineral Spring, Pulaski, Lawrence County.
Rennyson Tredyffrin Spring, Rennyson, Chester County.
Ross-common Springs, Windgap, Monroe County.
Saegertown Mineral Spring, Saegertown, Crawford County.
Sizer Mineral Spring, Sizerville, Cameron County.
Spruce Hollow Mineral Spring, near Northumberland, Northumberland County.
The J. W. Lang Mineral Well, Venango, Crawford County.
Tuckahoe Mineral Springs, Northumberland, Northumberland County.
Whann Alkaline Lithia Mineral Springs, near Franklin, Venango County.
White House Spring, Neversink Mountain, Reading, Berks County.

The aggregate amount of water sold in 1902 is given as 4,567,260 gallons, valued at $1,124,532.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

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Water resources of the Elders Ridge quadrangle, Pennsylvania, by R. W. Stone: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1904, pp. 164–165.

Water resources of the Waynesburg quadrangle, Pennsylvania, by R. W. Stone: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1904, pp. 166, 167.

Well records. (See reports of State Geological Survey of New Jersey.)

DELAWARE.

By N. H. Darton.

GEOLOGY.

This State lies almost entirely on the Coastal Plain, across which it extends diagonally to the Atlantic Ocean. The crystalline rocks emerge at the surface in the extreme northern portion of the State, but are deeply buried under the Coastal Plain deposits to the southeast. The general structure is shown in section 1, Pl. VII. The topography of the State is relatively simple, consisting of a general terrace plain averaging about 50 feet in altitude and a small area of higher rolling hills north and west of Wilmington. The geologic formations are as follows:

Formation.	Characteristics.	Age.
Columbia	Sands, loams, and gravel	Pleistocene.
Chesapeake	Sands, clays, infusorial earth, and marl.	Miocene.
Pamunkey	Brown sand and marl	Eocene.
Rancocas	Middle marl	Later Cretaceous.
Redbank	Sands and marl	Do.
Navesink	Lower marl	Do.
Matawan	Clay marl and sand	Do.
Raritan and Potomac	Clays and sands	Early Cretaceous.
Crystalline rocks	Granite, gneiss, gabbro, limestone, and quartzite.	

WATER HORIZONS.

As relatively few deep wells have been bored in Delaware, the water horizons have not been fully explored over a very wide area. The well at Middletown (see below) has obtained a fine supply of water from the Potomac formation, apparently from the basal beds, and it is probable that this water sheet extends from Wilmington past Middletown far southward. At Farnhurst it yields a moderate supply. The dip of the horizon to the south-southeast is about 30 feet to the mile,

which carries it from the tide level at Wilmington to a depth of 165 feet at Farnhurst and 535 feet at Middletown. Water horizons above the lower beds of the Potomac formation and in the Matawan, Redbank, and Lower Marl, that occur in New Jersey, were not reported in the Middletown well, which probably indicates that these waters do not extend into Delaware. The principal Chesapeake horizons appear to be represented in Delaware, although the evidence in regard to their correlation is not conclusive. The basal Chesapeake water, so important in Maryland, has not been reached by the wells. The water from sands in the great diatom bed (the 525-foot horizon at Atlantic City) probably supplies the Dover and Mahon River wells with their large yields, while Milford and Lewes apparently obtain their waters from a stratum that lies just above the diatom bed. As the Kitts Hummock well draws from a bed about 125 feet above the horizon of Dover and Mahon waters, its water horizon can not be definitely correlated with any of those at Atlantic City. The Ocean City well in Maryland is a high Chesapeake horizon which probably extends into the southern edge of Delaware, but no wells have yet been sunk to it in that State.

WATER SUPPLIES.

DEEP WELLS.

There are only a few deep wells in the State, but they are all successful and nearly all furnish large supplies of water. The following is a list of some of the more important ones:

Partial list of deep wells in Delaware.

Locality.	Depth.	Diameter.	Capacity per minute.	Height to which water rises.	Remarks.
	Feet.	*Inches.*	*Gallons.*	*Feet.*	
Dover	196	10	Flows 35; Pumps 218	+ 6	Water also at 157 feet.
Clayton	150	6	30	+20	No water at 85–150 feet.
Do	60	.....	.....	.....	
Do	85	.....	Moderate.	.....	
Farnhurst	211	.....	.....	.....	Water also at 40 and 60 feet; rock at 211 feet.
Kitts Hummock	110	1¼	Much.	− 2¼	
Lewes	400	6	15	To surface.	
Mahon River	206	.....	Much.	.....	
Middletown	535	10–8	330	−50	Fine quality of water; much water also at 475 and 530 feet.
Middletown	90	(?)	(?)	(?)	
Milford	160	4	60	+ 2	
Do	150	4	60	+ 3	
Do	34	4	50	.....	
Wilmington (Stoekle Brewery).	400	8	15–18	.....	In granite.
Wilmington (H. & F. Brewery).	1,077	.....	10	−25	In granite, 96–1,077 feet.
Wilmington (Hart & Bros.).	200	6	75	.....	In granite, 36–200 feet.

WELL PROSPECTS.

From the evidence furnished by wells now yielding water supplies, it appears probable that the entire Coastal Plain area of Delaware is underlain by water. About Middletown and to the north the Potomac waters may be expected at depths which decrease at the rate of 30 feet per mile nearly to Wilmington, where the Potomac beds come to the surface. These waters may extend down the dip south of Middletown for many miles, but as no wells have been bored to them in that region no positive prediction can now be made as to the probability of obtaining water there. At Dover they should be expected at about 1,000 feet below the surface, if the southward dip continues at a uniform rate.

The Chesapeake waters begin a couple of miles north of Clayton and extend to the southern border of the State. The basal Chesapeake waters, which are important sources of supply in Maryland and in areas farther south, have not been tested by any wells in Delaware, but may be expected to extend over a wide area. The Clayton boring to 150 feet nearly reached this horizon, which probably lies about 450 feet below the surface at Dover. The Dover waters no doubt are widespread, for they are probably the same as those found at 234 feet at Federalsburg. The water horizon which appears to extend from Milford to Lewes probably also underlies all of eastern Sussex County, but it is not reported in any of the Maryland wells. In both Kent and Sussex counties there are almost certain prospects for Chesapeake waters at one horizon or another within 500 feet of the surface. Sections 1 and 2, Pl. VII, show the conditions so far as there are any data to present concerning them.

PRINCIPAL PUBLICATIONS.

(Well records.) See reports of State Geological Survey of New Jersey.

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Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, 1902, p. 21.

MARYLAND.

By N. H. Darton and M. L. Fuller.[a]

TOPOGRAPHY AND GEOLOGY.

The surface of Maryland may be divided into four topographic belts, determined by the composition and structure of the underlying rocks. Three of these, the Piedmont Plateau, the Appalachian Mountain, and Allegheny Plateau belts, are continuations of those developed in Pennsylvania and described in connection with that State. In addition to these there is in Maryland the great Coastal Plain belt, which stretches southeastward from a line extending from near Havre de Grace through Baltimore and Washington to Chesapeake Bay and the Atlantic coast. The materials of this belt are unconsolidated clays, sands, and gravels, mainly of Cretaceous and Tertiary age. When originally deposited the beds were very nearly horizontal, but they have been since tilted so that they now dip considerably to the southeast.

The Coastal Plain is moderately low and where not eroded by streams exhibits flat surfaces. Such flat areas, however, because of the extent to which erosion has taken place, are of no great extent.

The rocks of the Piedmont Plateau are mainly crystalline and include granites, diorites, and other igneous or metamorphic rocks, together with some schists, slates, and crystalline limestones. In altitude the belt is somewhat higher than the Coastal Plain area. Like the latter, it shows, in those portions untouched by streams, a nearly flat surface due, however, in this instance, to long-continued erosion at a period when the rocks stood near sea level, rather than to nearly level deposition, as in the Coastal Plain. The rocks, though deeply weathered, are harder than the Coastal Plain deposits and are less readily gullied by small streams. Moreover, they have been subjected to erosion for a much longer period than those of the Coastal Plain and more rounded forms have been developed.

Bordering the crystalline area and included partly within the area of Ordovician rocks to the west is a belt of Triassic sandstones and

[a] The following account of the water resources of Maryland has been prepared by M. L. Fuller, but the portions relating to the Coastal Plain have been compiled from the report of Mr. N. H. Darton on Artesian-well prospects in the Atlantic Coastal Plain region: Bull. U. S. Geol. Survey No. 138, 1896.

shales that ranges in width from 2 to 15 miles. The topography of this belt is similar to that of the Piedmont belt.

The Appalachian Mountain belt, as in Pennsylvania, consists of a series of strongly folded Cambrian, Ordovician, Silurian, and Devonian rocks, including a number of quartzites, sandstones, and limestones, lying mainly between Emmitsburg and Cumberland and striking northeast-southwest. Beyond Cumberland the rocks consist of moderately folded Devonian and Carboniferous strata, the harder beds of which give rise to ridges. These ridges are not, however, so strongly developed as those lying farther east, and in the areas between them plateaus similar to those of western Pennsylvania have been developed. As in the latter State the plateau in Maryland is deeply cut by the streams which drain it.

WATER SUPPLIES.

SPRINGS.

Springs are numerous throughout Maryland, but it is only in the limestones or coarse sandstones of the strongly folded Appalachian belt that they are commonly of any considerable size. In rocks other than limestones and sandstones the springs, though numerous, are small, but they nevertheless supply pure water for a large number of inhabitants in the more thinly settled districts.

In the crystalline rocks of the Piedmont Plateau springs are less common and are generally of small volume, but because of the demand for pure water for drinking purposes in the larger cities a number of such springs have been developed and their waters placed on the market. These are mainly in the vicinity of Washington and Baltimore.

The more porous beds of the Coastal Plain, where cut by ravines, give rise to numerous springs. These are commonly small and their water is frequently hard and is unsatisfactory for many purposes. Relatively little use is generally made of these springs, but a few of them that possess medicinal properties have been developed and their waters placed on the market.

The following is a list of springs reporting shipments in 1902:[a]

Blackiston Island Diuretic Mineral Spring, Blackiston Island, St. Mary County.
Bladensburg Spa, Bladensburg, Prince George County.
Carroll Springs, Forest Glen, Montgomery County.
Chattolanee Springs, Chattolanee, Baltimore County.
Elim or Willmead Spring, Oxenhill, Prince George County.
Mardela Mineral Spring, Mardela, Wicomico County.
Rock Hill Indian Spring, Rockville, Montgomery County.
Roland Park Artesian Well, Roland Park, Baltimore County.
Takoma Spring, Takoma Park, Montgomery County.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

Of these springs those in St. Mary, Prince George, and Wicomico counties are from Coastal Plain deposits. The remainder are probably from the crystalline rocks of the Piedmont Plateau. The aggregate production for 1902 is given as 488,228 gallons, with a value of $45,100.

STREAMS.

The small streams in the mountainous regions of Maryland are mainly spring-fed and contain in their upper courses very pure water. They soon become contaminated, however, by refuse from manufactories and villages situated along their courses, and, although frequently used as a source of water supply, they can not be regarded as a desirable source of water for domestic use. Moreover, they are often highly charged with silt.

The streams of the Piedmont and Coastal Plain belts are, because of the relative density of population of those areas, even more liable to pollution than those of the mountainous area and are seldom, if ever, desirable sources of supply.

WELLS.

Allegheny Plateau.—The Allegheny Plateau is developed only over a limited area in the extreme western part of the State. It is cut by the Potomac and Youghiogheny rivers and abounds in smaller streams. Springs are also common in this region. The surface waters are so abundant that the relatively small population depends largely on natural water supplies, very few wells being sunk except in the river bottoms, where good water is obtained at slight depth. Such wells as have been drilled, however, have generally procured considerable water from the shales and sandstones of the Carboniferous and Devonian. Several wells in the synclines or basins yield flowing water.

Appalachian Mountains.—There are a few wells in the river bottoms and there is an occasional shallow rock well in the limestone or shale valleys in the Appalachian Mountain belt, but deep wells are lacking, springs constituting almost the only source of natural supply. Cisterns are sometimes used.

Piedmont Plateau.—The surface of the Piedmont Plateau is here, as elsewhere, made up of more or less deeply weathered and jointed crystalline rocks. These contain considerable water in the aggregate, many shallow wells deriving their supplies from their weathered upper portions, while other wells obtain water from joint fissures at greater depths. The occurrence or nonoccurrence of water at a given point can seldom be predicted, however, because of the great variability of the governing factors. The largest supplies are obtained from these rocks near the cities of Baltimore and Washington, each of which is discussed separately.

Coastal Plain.—The Coastal Plain region in eastern Maryland presents the usual general structural relations, but certain local features are conspicuous. The Raritan formation merges into the underlying Potomac formation; the upper marl of the marine Cretaceous thins and changes to more clayey beds, and only the middle and lower members continue southward, where they have been designated the Severn formation; the Pamunkey greensand marl comes in, and the plateau areas capped by the Lafayette formation become characteristic features. The formations are as follows:

Coastal Plain formations in Maryland.

Formation.	Characteristics.	Age.
Columbia	Loams, sands, and gravels on terraces	Quaternary.
Lafayette	Gravel, sands, and loams	Pliocene?
Chesapeake	Sands, clays, infusorial earth, and marl	Miocene.
Pamunkey	Glauconitic marls and sands	Eocene.
Severn	Black argillaceous, carbonaceous sands	Cretaceous.
Magothy	White sands and brown sandstones	Cretaceous.
Potomac	Clay, sands, and gravels	Early Cretaceous.

In the following table is given a list of the more important localities obtaining deep or artesian waters. Baltimore wells are not given, but are considered on a subsequent page:

Statistics of deep-well localities in Maryland.

Locality.	Range of depth.		Range of capacity per minute.		Geologic horizon of water.
	From—	To—	From—	To—	
	Feet.	*Feet.*	*Gallons.*	*Gallons.*	
Agricultural College		150		5	Basal Potomac.
Annapolis		201			Magothy.
Bay Ridge		470		20	Mid-Potomac.
Bowie		384	0		In Potomac.
Bushwood		287			Low in Pamunkey.
Cambridge, 6 wells		370	160	each, 250	Basal Chesapeake.
Chapel Point		237			Basal Pamunkey.
Claiborne	100	440		Many	Magothy, in Pamunkey.
Cornfield Harbor		360			Basal Chesapeake.
On farm	240	370			Chesapeake, Basal Chesapeake.
Crisfield	1,018	1,090	40	200	Magothy, Potomac.
Denton		359		30	
Easton, 6 wells	102	600	0	each, 75	Low in Chesapeake, Into Pamunkey, Low in Severn?
Federalsburg		234		20	In Chesapeake.
Indian Head		463¼		11¼	In Potomac.
Laurel		148¼		10	Basal Potomac.
Le Compt's store		358		4	Basal Chesapeake.
Leonardtown		300		2	Do.
Marlboro		222		25	Magothy?

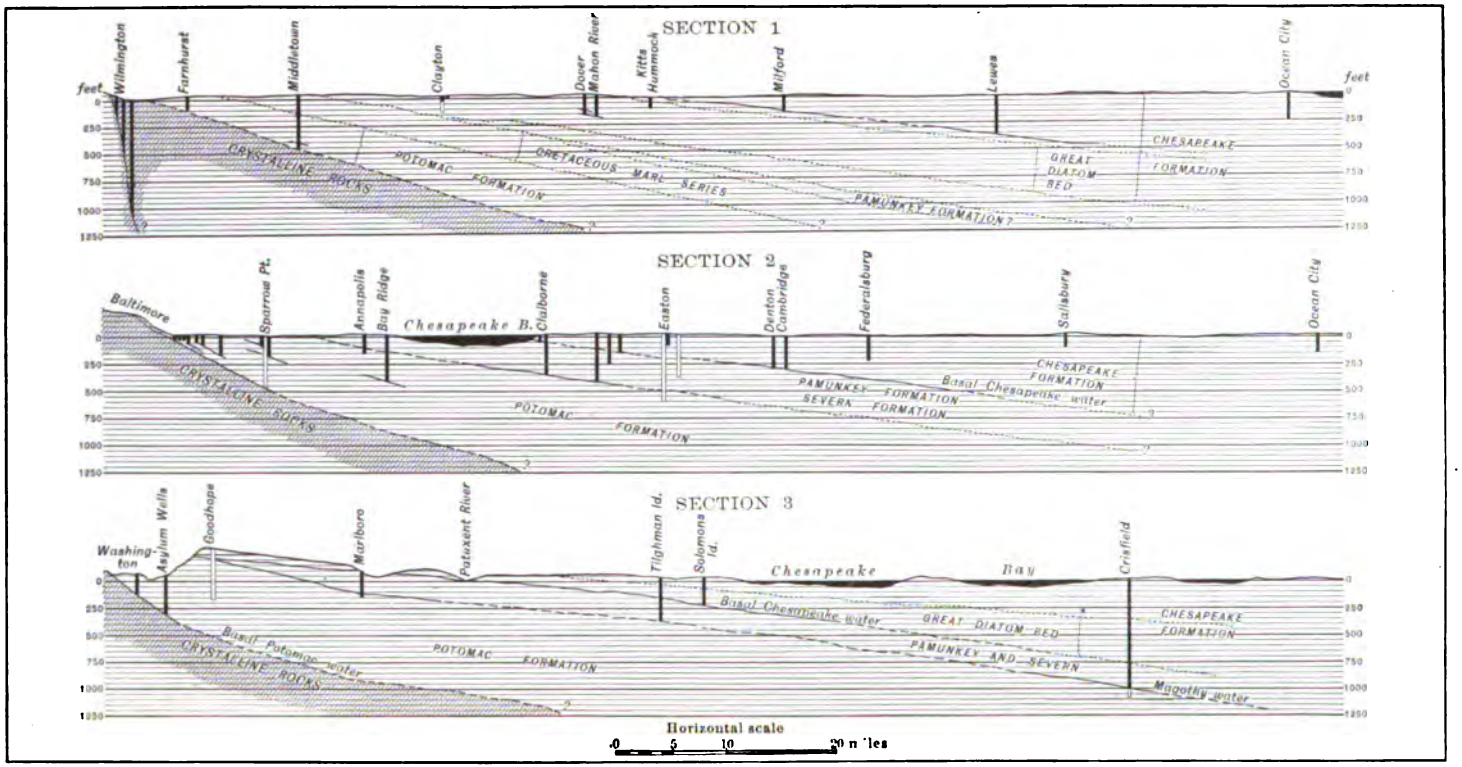
Statistics of deep-well localities in Maryland—Continued.

Locality.	Range of depth.		Range of capacity per minute.		Geologic horizon of water.
	From—	To—	From—	To—	
	Feet.	*Feet.*	*Gallons.*	*Gallons.*	
Miles River Neck ("Anchorage")	.....	265	.....	15	In Pamunkey.
Miles River Neck (Long Point)	.....	195	.....	5	Basal Chesapeake.
Nanjemoy (Landing)	.....	175	.....	1	Basal Pamunkey.
Oakley	.....	305	.....	7	Low in Pamunkey.
Ocean City	.....	256	.....	130	High in Chesapeake.
Patuxent River, at B. & P. R. R.	.....	152	.....	20	Basal Potomac?
Piney Point	.....	270	.....	5 (?)	Basal Chesapeake.
Rousby on Patuxent	.....	240	.....	Many.	Do.
Rock Point, Charles County.	.....	254	.....	3	Do.
St. George Island, 25 wells.	.....	270	.....	each, 2-5	Do.
St. Inigoes, 10 wells, "Jutland."	.....	365	.....	1	Do.
Salisbury	.....	101	.....	350	High in Chesapeake.
Solomons Island, 2 wells.	252	258	10	each, 150	Basal Chesapeake.
Tilghman Island	.....	400	.....	Many.	Magothy?
Tunis Mills, on Miles River Neck.	.....	430	Flows, 6	Pumps, 100	Do.

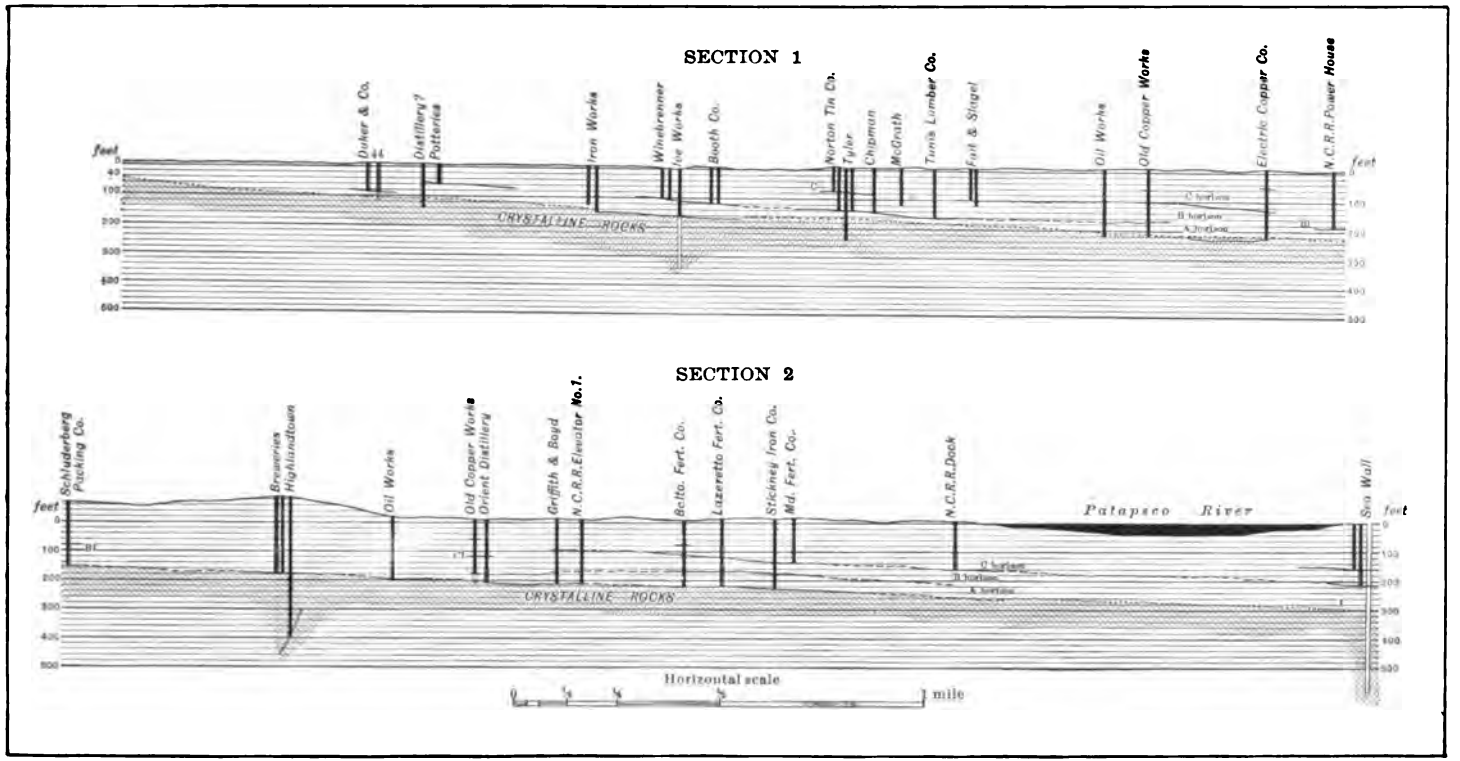
WATER HORIZONS.

It is now known that the greater part of the entire Coastal Plain region of Maryland is underlain by several horizons of water-bearing beds. The distribution of wells and water horizons is represented in the cross sections of Pl. VII.

The gravels and sands of the basal beds of the Potomac formation that lie on or near the floor of crystalline rocks are the principal sources of water for wells sunk in the western portion of the Coastal Plain. How far southeastward this water horizon may extend has not been determined, but probably it will yield water in many areas nearly to the Atlantic coast. To the east and south the dip of the Potomac horizon carries it to a great depth, but there are several strata of water in higher beds in the Potomac, and in other formations at more moderate depths. The easternmost successful wells which have reached the base of the Potomac formation are those in the southeastern portion of the Baltimore region, in the District of Columbia, and at Middletown, in Delaware, all of which are only a few miles from the outcrop of the formation, so that the eastern extension of the basal Potomac waters is not known over a very great breadth of territory. The failure of a well at Sparrow Point to find water in the basal beds indicates also that the sheet of water is not general at this horizon.



SECTIONS IN MARYLAND AND DELAWARE.



SECTIONS IN BALTIMORE REGION.

The water horizons lying at various distances above the basal beds, but within the Potomac formation, have been extensively explored in the vicinity of Washington and Baltimore, where they appear to be widespread and satisfactorily productive. They have also been reached in a Marlboro well at a depth of 216 feet, and in a well at Indian Head at 459 feet. A well at Bowie found no satisfactory supply of water to within about 200 feet of the base of the formation, nor was a well on Spesutie Island a success, though it appears to have penetrated the Potomac beds to a considerable distance. The sands of the Magothy formation, which underlie the Potomac, appear to be water bearers over a wide area on the Eastern Shore of Maryland, as is probably indicated by wells at Claiborne, Tilghman Island, and Crisfield, and possibly also at Tunis Mills. They underlie the central area of the Western Shore southeast of a line from Bowie to the mouth of the Patapsco River, but do not appear to yield water in Marlboro, Annapolis, and Bay Ridge wells. A boring to 600 feet at Easton, unfortunately, probably did not thoroughly test this horizon, otherwise we might have had some important evidence for that portion of the Eastern Shore region. A 265-foot well on Miles River Neck appears to draw its water from a horizon in the Pamunkey formation, but this well is the only indication of a water horizon in these formations in the Eastern Shore region. In wells at Colonial Beach, Va., and at Nanjemoy, Chapel Point, and Rock Point, in Charles County, the basal Pamunkey beds yield water which probably underlies much of southern Maryland southeast of a line from Herring Bay to Liverpool Point.

The basal Chesapeake water horizon, which is well explored in Virginia, yields water over a wide area in the southern counties of the Western Shore at depths from 200 to 300 feet, as in wells at Solomons Island, Leonardtown, Piney Point, St. Inigoes, and St. Georges Island. At Cornfield Harbor it is 365 feet. This horizon also furnishes large water supplies at Denton, Cambridge, and Le Compt's store, and possibly in a well 195 feet deep on Miles River Neck, on the Eastern Shore. It was not found at Crisfield, nor in a deeper boring at Easton, although the associated sandstone bed was reported at Easton. The higher Chesapeake horizons are important in New Jersey and Delaware, and, although not extensively tested in southern Maryland, they probably underlie a considerable area of the Eastern Shore. At Easton the large water supply in wells 100 feet deep is derived from a horizon in the Chesapeake formation about 150 feet above its base, and the Federalsburg water, which lies at a depth of 234 feet, is either at the same horizon or at one not a great distance above. The small showing of water at 160 feet at Leonardtown appears to be a local occurrence, for it was not reported in other wells to the east. Unsatisfactory water was obtained at Salisbury from a much higher horizon,

and the flow of fine water at Ocean City is from a still higher horizon of the Chesapeake formation. In the wells at and near Cambridge and at Crisfield no waters were reported above the basal Chesapeake beds; so we must conclude that the higher waters do not extend in that direction.

BALTIMORE DISTRICT.

GEOLOGY.

Baltimore lies in the zone in which the crystalline rocks emerge from beneath the Coastal Plain deposits. Although in greater part it is built on the Potomac formation, the depressions of Jones and Gwynns falls are excavated to the crystalline rocks, and these rocks rise rapidly to constitute the surface in the region north and west of the city. The Potomac formation consists of its usual materials, in which predominate clays of various colors and fine sands. Toward its base there are beds of coarse sands and gravels, and at the base an almost general occurrence of these materials, lying on a floor of crystalline rocks. Some features and relations of these basal beds are shown in Pl. VIII. The coarse materials contain widely extended sheets of water, which have been tapped by many well borings of moderate depth. The rock floor slopes rather steeply eastward, at a rate averaging about 65 feet per mile, but the rate appears to increase locally to 100 feet along by the Basin. The basal gravels pass beneath tide water along a line extending from the lower Baltimore and Ohio Railroad bridge over Gwynns Falls to the Fayette Street Bridge over Jones Falls, and thence due east-northeastward. The principal water supplies are found south of this line, for in the area to the north the waters are free to flow laterally into the depressions of Jones and Gwynns falls. The basal gravels emerge in the northern portion of the city, although in some areas they are overlain by a thin cap of gravels and loams of earlier (Columbia) age. They cap the Druid Hill Park region, the ridges for some distance out Charles street, Roland avenue, and York, Harford, and Belair roads, and the high region about Catonsville. In these outlying extensions the basal gravels constitute a capping on the crystalline rocks which averages from 10 to 30 feet in thickness. The principal structural relations are shown in the sections on Pl. VIII. On Patapsco River Neck the Potomac formation rapidly thickens as the crystalline rock floor descends to the east, and at Sparrow Point its thickness was found to be 500 feet. The higher ridge which extends along the northern portion of this neck is capped by a thin mantle of earlier Columbia gravels and loams, and the lower terraces consist of later Columbia loams and sands, with some gravel in the lower beds. These formations, however, are not involved in the question of the deeper water supply.

The crystalline rocks present considerable variety of materials, but gneiss and granite, or "gray stone," and "nigger head," or gabbro, are the most conspicuous varieties. They are all considerably fissured and often deeply decomposed along fissures or veins of moderate width and extent. The fissures or veins are usually nearly vertical and extend from northeast to southwest. They are water-bearers in greater or less measure, but their distribution and extent have not been determined, except in the case of the one along Belair road, which has been tested for a short distance.

WATER HORIZONS AND WELL PROSPECTS.

Canton.—The wells in Canton indicate the presence of several widely extended sheets of water-bearing gravels, the upper layers of which are interbedded between sheets of clay and fine sand, the lower bed lying on the floor of crystalline rocks. The dip is to the southeast at rate of about 60 feet per mile. In Pl. VIII the first section lies along Clinton street from Highlandtown to Thirteenth avenue and across Patapsco River to Seawall. The three principal water horizons are lettered A, B, and C. They occur from the bed rock up at intervals that average 40 feet.

There are several wells north of Canton, at Highlandtown, which yield large water supplies. At the National Brewery there are two wells to 240 and 450 feet, and at Gunther's brewery two wells to 207 and 208 feet. The waters at 207 and 240 feet are probably in basal Potomac beds, or at Horizon A, as shown in section 1, Pl. VIII. At Schluderberg's packing house a well yields water at 135, 160, and 210 feet, and the 160-foot or third horizon was tested to 150 gallons a minute. The basal beds of the Potomac formation probably carry the water found at 210 feet.

East Baltimore, from Canton to the Basin.—There are only a few wells in the vicinity of Jones Falls, and they are not very successful, but from the foot of Patuxent street to Ann street there are 25 wells, nearly all of which are large producers of excellent water. The average depth is between 80 and 120 feet, and the principal water horizon is B of the Canton region, but A and C also are found. Section 2 of Pl. VIII illustrates the principal relations.

The large water supply found in the basal Potomac beds, Horizon A, appears to extend to the north and west, but it was not reported half a mile southeast. The greater number of the wells in this district find abundance of water in Horizon B, about 40 feet above the basal beds.

What appear to be the sea horizons of the Canton region yield water in places.

In the region immediately adjoining Jones Falls and for some distance to the west on the north side of the Basin deep wells do not yield

satisfactory water supplies on account of the proximity of the basal and lower Potomac beds to the surface. Several wells have penetrated the crystalline rocks and found a fair supply of satisfactory water.

Region between the Basin and the harbor and Middle Branch.—There are several wells along the north side of Locust Point from the Basin to Fort McHenry, which yield satisfactory water supplies from the Potomac horizons.

Probably Horizons B and C underlie all of the Locust Point region, and Horizon A, in the basal beds, may possibly occur at some localities southeast of the Federal Hill region.

On the Ferry Bar peninsula there are a few widely scattered wells, which, however, indicate that the favorable conditions in Canton and on Locust Point continue to the west, and that abundant waters may be obtained in Horizons C, B, and A. The shallower waters are unsatisfactory in quality, but the deeper waters give no scale in boilers and occur in large amounts.

Between the Basin and Ridgely Cove a number of attempts have been made to obtain water from the crystalline rocks, with varying degrees of success.

Region from Brooklyn to Curtis Bay.—The successful group of wells at Seawall and at South Baltimore (Curtis Bay) indicates a wide and general extension of the Potomac waters under the Curtis Bay-Patapsco River peninsula. The Seawall water at 217 feet appears to represent Horizon C. The 562-foot boring at Seawall no doubt demonstrates the absence of water in the basal Potomac, or Horizon A, in that vicinity, and also in the underlying crystalline rocks.

Region southeast of Canton to Sparrow Point.—The wells of St. Helena, Dundalk, and Sparrow Point are included under this heading. Their relations are shown in section 2, Pl. VIII. The wells at St. Helena are probably in Horizon C, and the water at 230 feet at Dundalk is thought to be in Horizon B, which probably would have been found at 200 feet at St. Helena. The 120-foot water at Dundalk is possibly the deepest water of Sparrow Point.

The Sparrow Point wells are a most satisfactory group of water producers. Their principal supply is obtained at a depth of 125 feet from a horizon high in the Potomac formation, for a well sunk to a depth of 495 feet just reached the granite bed rock. In this deep well no water was found below 210 feet, which indicates that the lower water horizons do not extend far eastward in this region. The one well which draws 100 gallons a minute from a depth of 210 feet obtains its supply from a horizon which can not be definitely correlated with those of wells farther northwest.

Northeast Baltimore.—Several breweries in this section of the city have deep wells, some of which yield satisfactory water supplies. They all penetrate the crystalline rocks and obtain water from fissures

or decomposed portions of these rocks in fair supply, but when wells were sunk to 315 and 400 feet at the Bauernschmidt brewery, a block southwest, the supply at once diminished to a very small amount. The well at the Brehm brewery, which is some distance east of the Belair road and several squares beyond North avenue, was sunk in the rock to a depth of 1,300 feet without finding water, but it is considerably east of the line of the other wells.

The Darley Park Brewery well, on the Harford road, three squares north of North avenue, is west of the Belair-Gay street line of wells. The waters from these wells differ considerably in character, but in greater part they are satisfactory for boilers and drinking, although in some cases the water is too ferruginous for general use.

Western part of Baltimore.—Except the well at the Lipp Soap Works, at Hollins street and Calverton Road, no specific data for borings in the western part of Baltimore are at hand. The soap works wells are in crystalline rocks and reach a vein or fissure which yields a good supply of water of excellent quality.

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DISTRICT OF COLUMBIA.

By N. H. Darton and M. L. Fuller.

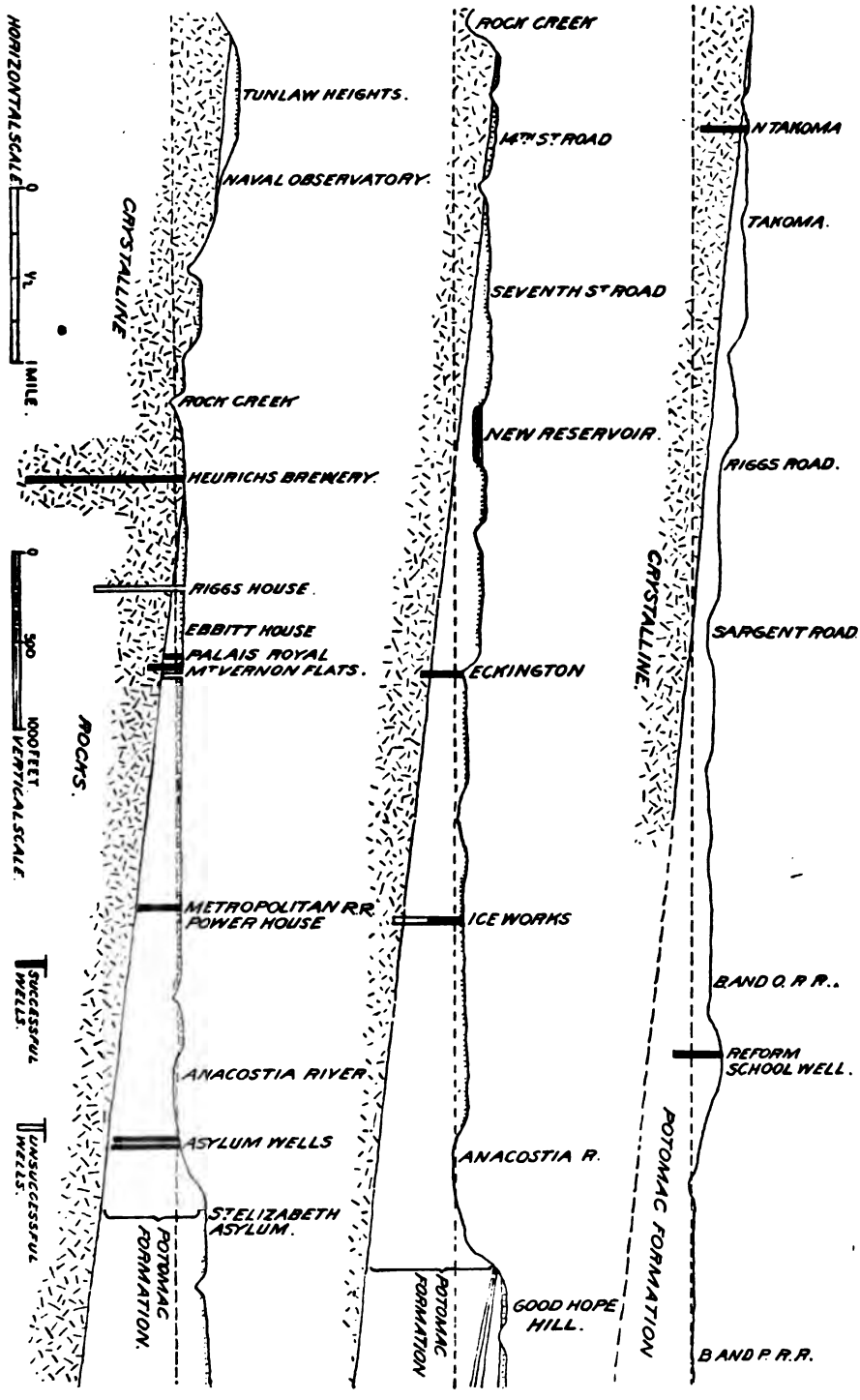
GEOLOGY.

The District of Columbia extends across the zone in which the crystalline rocks emerge from beneath the Coastal Plain deposits and rise into the Piedmont Plateau to the west. The contact line crosses the Potomac River at Washington, passes through the western portion of the city, and extends northward along the east side of Rock Creek Valley. The formation that lies on the crystalline rocks is the Potomac, which consists mainly of water-bearing sands and gravels below and of clay and fine sands above. The Potomac formation has in all a thickness of about 700 feet, and outcrops in a belt from 7 to 8 miles wide, which extends eastward high up the slopes on the east side of Anacostia River. In these slopes it is surmounted by younger formations, consisting of a succession of the thin western edges of the dark sandy clays of the Severn formation, the impure marl of the Pamunkey, the gray clays of the Chesapeake, and the gravels of the Lafayette. Washington is situated on a series of broad, low terraces cut in Potomac sands and clays and across the edge of this formation into the crystalline rocks.

This series of terraces and its extension along all the lower land of the District is capped by from 20 to 35 feet of gravelly sands and loams of the Columbia formation. In the three sections in Pl. IX a fairly clear representation is given of the structure of the Washington region. It is in Good Hope Hill that the Potomac formation passes under the Severn, Pamunkey, Chesapeake, and Lafayette formations, as shown in section 2, but there are also small outlying areas of the Chesapeake and Lafayette formations on the high lands of Soldiers' Home Park and the ridge which extends to Tenley.

WATER HORIZONS AND PROSPECTS.

Waters of the crystalline rocks.—Under this head are included the waters of the consolidated rocks of the Piedmont Plateau portion of the District. These rocks comprise granite-gneiss, biotite-granite, diorite, etc., and are generally deeply weathered and cut by numerous



SECTIONS IN DISTRICT OF COLUMBIA.

joints. The disintegrated nature of the outcrops is favorable to the absorption of considerable quantities of water and the broken-up rock acts as a filter. In general, the area of the consolidated rocks is relatively thinly settled and little demand is made on it for water supplies, except by shallow wells. The few deep wells that have been put down, however, show that moderate amounts of good water can frequently be obtained, although, because of variations in the density of the rock and in the number of joint fissures, the conditions are far from constant.

The surface of the consolidated rocks slopes southeastward from Rock Creek, where it is exposed at an elevation of 200 feet, at an average rate of 110 feet to the mile. It lies at a depth of about 100 feet below tide level in the center of the District and of about 600 feet at the southeastern boundary. The crystalline rocks are not depended upon as a source of water east of Rock Creek because of the greater quantities that are found in the sedimentary beds that overlie them in this region.

Waters of the sedimentary rocks.—All of the sedimentary formations carry more or less water, but, except in the case of the Potomac, the flows are small and the quality is not the best. This is especially true in the isolated areas capping the hills of crystalline rocks, even the Potomac frequently failing in such localities.

The Potomac is the principal water-bearing formation of the area; it constitutes the surface material over most of the Coastal Plain portion of the District, having a catchment area from 6 to 8 miles in width. Its base rests on the crystalline rocks, dipping southeastward with the latter. Its total thickness, as pointed out, is about 700 feet.

The deeper-seated underground waters have been tapped by a sufficiently large number of wells in the District to demonstrate the almost general extension of water-bearing beds in the basal and lower bed of the Potomac formation, and there is often a fair prospect for finding water in the crystalline rocks. The wells that did not find a satisfactory water supply in the basal Potomac beds are at the Ice Works at a depth of 360 feet, and at the Mount Vernon Apartment House at 133 feet. On the other hand, the St. Elizabeth, Metropolitan Railroad power house, Palais Royal, Eckington, Washington Brewery, and National Capitol Brewery wells obtain large supplies from that horizon. In surface outcrops the basal Potomac beds are usually coarse sands and gravels, which are filled with water, but there are some local areas in which there is a clay matrix, or even pure clay, extending down to the crystalline floor. This was found to be the case at the Mount Vernon Apartment House, while at the Palais Royal, three squares southwest, the basal beds were coarse sands and gravels containing much water. In the 380-foot well at the Ice Works coarse

basal beds were found, but they contain no large supply of water. This leads to the conclusion that the waters are in part choked off toward the north by a local area of clayey beds which does not influence the wells at the breweries near by.

Besides the basal sands and gravels of the Potomac there are beds of sand or gravel at several other horizons, especially near the top. Although of somewhat uncertain persistence and character they are so numerous that good flows can generally be obtained at or even considerably above sea level. As these beds occur in the District only near its southeastern border they are not here important sources of water, the underground water supply of the District being derived, as stated, mainly from the lower beds.

In general the dip of the Potomac formation corresponds roughly with the slope of the surface of the underlying crystalline rocks, decreasing from an elevation of 200 feet above sea level just east of the Zoological Park to sea level in the vicinity of New Hampshire avenue, 200 feet below sea level at the Capitol, 300 feet at Lincoln Park, 400 feet near Anacostia River, and 600 feet at the District line; hence there is a constant increase southeastward in the depths to which wells must be sunk to the water-bearing beds.

In general it may be said that the prospects are good for obtaining supplies from the basal beds of the Potomac, while there is always an additional chance of finding water in the overlying beds, as at the ice works. Notwithstanding the density of the population of almost the entire catchment area in the District, the organic impurities of the water are largely oxidized and removed in consequence of the natural filtration through the soil and sands, so that the supply from deep wells is usually satisfactory as regards purity.

Mineral springs.—Springs are fairly numerous in the District of Columbia, but in general consist only of small seeps from the disintegrated crystalline rocks or from the sandy portions of the Coastal Plain formations. A number have been developed, however, and water to the amount of 212,100 gallons, with a value of $12,105, was placed on the market in 1902.[a] These are listed below:

Columbia Natural Lithia Spring, Washington.
Crystal Spring, Washington.
Gitchie Crystal Spring, Benning.
Laurelwood Spring, Mount Pleasant.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

VIRGINIA.

By N. H. Darton and M. L. Fuller.

PHYSIOGRAPHIC DIVISIONS.

There are four well-defined geologic and topographic belts in Virginia: (1) The Coastal Plain, (2) the Piedmont Plateau, (3) the Appalachian Mountain belt, and (4) the Cumberland Plateau. The first three are prolongations of the belts of the same name in Maryland, with which they agree in character. The fourth corresponds in a general way with the Allegheny Plateau of Pennsylvania and Maryland, although its surface was not produced at the same geologic period.

GEOLOGY AND WATER HORIZONS.

COASTAL PLAIN.

GEOLOGY.

The Coastal Plain region of Virginia lies east of a line which passes through Alexandria, Fredericksburg, Bothwell, Richmond, Petersburg, and Emporia, comprising an area of about 9,500 square miles. This district is traversed from northwest to southeast by a series of great rivers, which divide it into a succession of long ridges. These ridges are remnants of a plateau surface which slopes from an altitude of from 300 to 200 feet at the western margin of the Coastal Plain to an altitude of about 100 feet on its eastern margin. The larger rivers are tidal estuaries that occupy low valleys and meander through wide terrace plains. Chesapeake Bay is widely bordered by these interstream terraces, while the Eastern Shore of Virginia, which lies east of the bay, is a low plain, as is also the wide area which lies between Dismal Swamp and the Atlantic Ocean.

The geologic structure of the region is in general similar to that of eastern Maryland, but there are certain differences in the stratigraphy. In the outcrop zone the Potomac formation becomes predominantly sandy and the Severn and Magothy sands are absent, so that the Pamunkey marls lie directly on the surface of the Potomac beds. Far eastward, under the bay and the Eastern Shore, there is probably

presented the same sequence that is found in Maryland. The Chesapeake formation extends farther westward in southern Virginia and often overlaps on the crystalline rocks. In the sections, Pl. X, there are shown the general structural relations in Virginia so far as they are known. The Coastal Plain formations that outcrop in the State are as follows:

Coastal Plain formations in Virginia.

Formation.	Characteristics.	Age.
Columbia	Loams, sands, and gravels in terraces	Pleistocene.
Lafayette	Orange sands, loams, and gravels	Pliocene?
Chesapeake	Clays, sands, infusorial earth, and marl	Miocene.
Pamunkey	Glauconitic marls and sands	Eocene.
Potomac	Sands, sandstone, and clays	Early Cretaceous.

WATER HORIZONS.

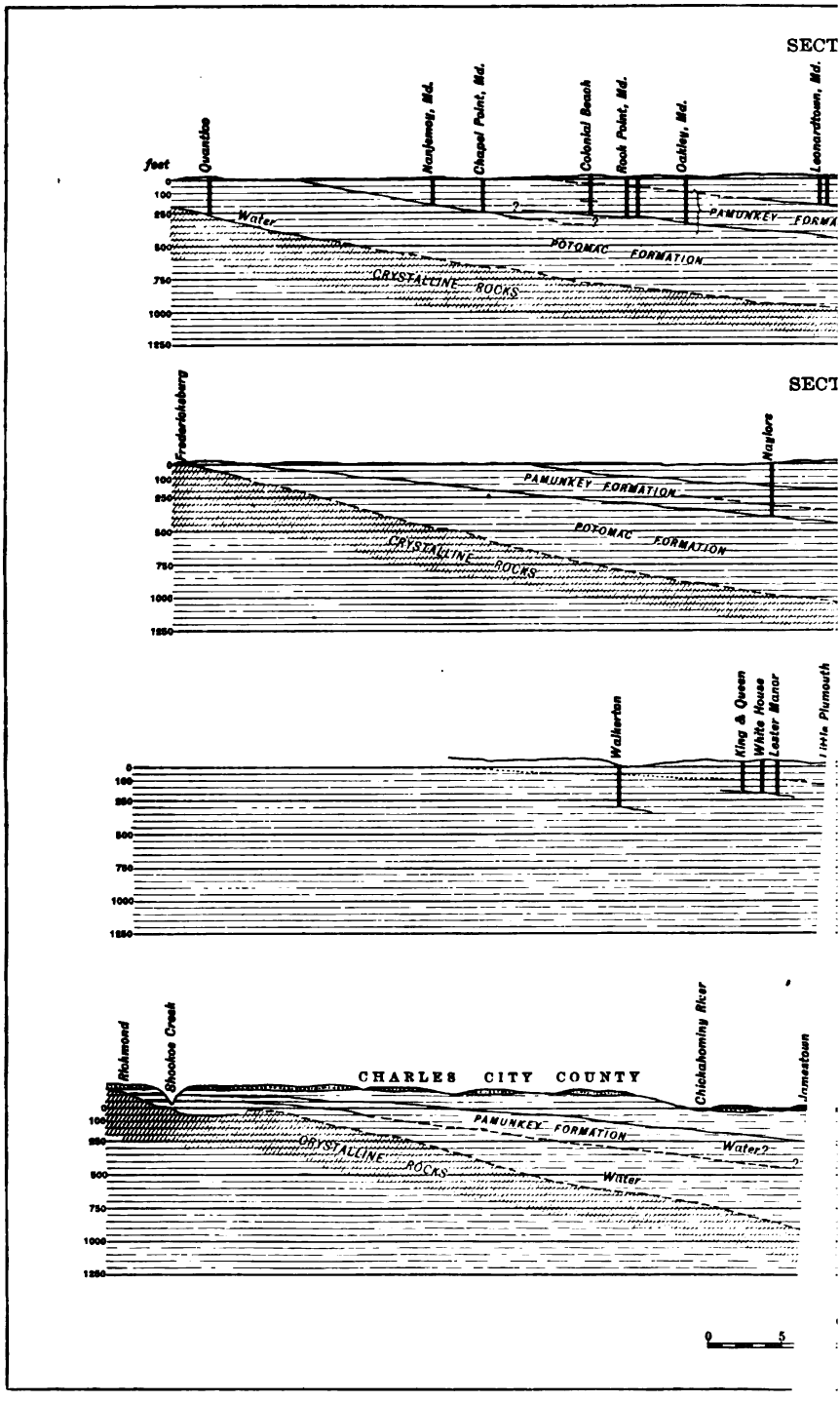
The greater part, if not all, of the Coastal Plain region of Virginia is underlain by water-bearing strata, of which, to the east, there are several horizons. The failures to obtain the higher water in some of the wells near the bay indicate that in this area at least there are no good water supplies in the higher horizons, but the waters of the lower horizons have not yet been fully developed. The success of the new well at Fort Monroe definitely proves the existence of one of these. The failure of a single well, as at North End Point, does not always disprove the existence of a water horizon, for in many instances water has been passed unnoticed, or willfully, by well borers.

The principal water horizons in eastern Virginia are the Chesapeake, the Pamunkey, and the Potomac.

Potomac.—There is more or less water in all of the coarser sand beds of the Potomac formation, but the principal supplies may be expected from the sands and gravels of the basal members lying on the basement floor of crystalline rocks. This horizon has yielded much water about Washington, Alexandria, Quantico, and Walkerton. It is probably a strong water-bearer throughout a wide extent. Its general relations are shown in Pl. X.

Water occurs at various horizons in the Potomac formation above the basal beds in sands interbedded among the clays. This water is an important source of supply in the District of Columbia and at Barrow, near Quantico, but elsewhere it has not been fully tested.

Pamunkey.—The coarse gravel and sand at the base of this formation appears to be a water-bearer throughout a considerable area, furnishing supplies at Naylors Wharf, Chapel Point, Md., Colonial Beach, Lester Manor, and Whitehouse.


SECT
Quantico
Nanjemoy, Md.
Chapel Point, Md.
Colonial Beach
Rock Point, Md.
Oakley, Md.
Leonardtown, Md.
feet
0
100
250
500
750
1000
1250
Water
PAMUNKEY FORMA
POTOMAC FORMATION
CRYSTALLINE ROCKS
SECT
Fredericksburg
Naylors
PAMUNKEY FORMATION
POTOMAC FORMATION
CRYSTALLINE ROCKS
Walkerton
King & Queen
White House
Lester Manor
Isle Plumouth
Richmond
Shockoe Creek
CHARLES CITY COUNTY
Chickahominy River
Jamestown
PAMUNKEY FORMATION
Water?
CRYSTALLINE ROCKS
Water
0
5

SECTIONS

The meager supply of water in the Clay Bank well and the failure of the deeper borings at Williamsburg and Gloucester probably indicate the eastern limits of the horizon as a water-bearer. It may extend under all of the region south of the James River, although none of the wells appear to have been bored sufficiently deep to reach it. It is to be expected that toward the east the materials at this horizon finally become too fine-grained to carry water, and the eastern limit of conditions favorable for water bearing appears to be at Clay Bank, on York River.

Water also occurs in sands in the Pamunkey formation about 90 feet above its base, as is indicated by the water at 160 feet at Colonial Beach, and at 275 to 325 feet at Naylors Wharf; but as it has not been further explored by other wells, its extent can not be discussed.

Chesapeake.—Lying between the clays, marls, and fine sands of the Chesapeake formation and the top of the Pamunkey formation there is a series of sands and gravels which may be regarded as the basal bed of the Chesapeake formation. Toward the east this series contains thin interstratified rock strata, which do not appear in the surface outcrops. In this series, and in another similar one not far above, there is a large volume of water, at a horizon or horizons which appear to be of wide extent in eastern Virginia. These waters have been explored by many wells and have been found to underlie a belt of country about 20 miles wide lying east of a nearly straight line extending from Mathias Point, on the Potomac River, to Emporia, on the Atlantic Coast Line Railroad.

Basal Chesapeake waters were apparently absent in the North End Point, Fort Monroe, Dendron, Clay Bank, and Gloucester wells. The wells at Crisfield, Md., found no appreciable supply of water in the basal Chesapeake beds.

There are several higher water horizons in the Chesapeake formation, and it is believed that certain wells at Franklin, Zuni, Bowlers Wharf, and Mount Carmel draw water from Chesapeake beds that lie about 100 feet above the base of the formation.

WELLS.

The occurrence of the underground waters is well brought out by the list of some of the more important wells of the Coastal Plain presented in the following table. It will be noted that the supply per minute and the bed from which the water is obtained is indicated in each case.

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Partial list of deep wells.

Location.	Depth.	Size.	Capacity per minute.	Height to which water rises. [a]	Horizon.	Remarks.
	Feet.	*In.*	*Gallons.*	*Feet.*		
Alexandria Brewery.	430	8	90	.....	Basal Potomac.....	Soft water.
Alexandria Ice Works.	401	8	20	−12	.....	Poor water at 300 feet.
Arringdale, 2 wells..	75	.....	Flows 10	+10	.....	Slightly alkaline water.
Ashland.....	79	1¼	Many.	−4¼	Granite?	
Do.....	100	4	Many.	.....	Granite	
Barrow	195	.....	Many.	.....	In Potomac	No water below 143 feet.
Bellevue, 2 wells	212	1¼	Flows 15 to 20	+4 to +6	Basal Chesapeake..	
Bothwell	300	6	20	−7	Newark	
Bowlers Wharf	143	4	7	Flows.	Chesapeake.....	Soft water.
Carters Creek.....	330	.....	.....	+12	.....do.....	
Clay Bank.....	538	1¼	Flows 2	+4	Basal Pamunkey?..	
Clifton, 2 wells	175	1¼	Flows 10 to 12.	+4 to +6	.....do.....	
Coan, 8 wells	270	1¼	Flows 2¼	+12	Basal Chesapeake..	Water also at 240 feet.
Coan, 1 well.....	315	4	15	+12	.....do.....	
Coles Point.....	220	1¼	3	+12	.....do.....	
Colonial Beach, 5 wells.	250	1¼	5	+8 to +15	Basal Pamunkey ..	Water also at 160 feet.
Courtland, 30 wells..	160	.....	30	.....	Chesapeake?.....	
Cowart	288	2	Flows 2	+6	Basal Chesapeake..	
Ditchley.....	620	1¼	Flows 2	+4 to +6	.....	
Dendron.....	386	6	None.	.....	.....	
Dudleys Ferry, 4 wells.	175	1¼	Flows 10	4 to 6	Basal Chesapeake..	
Dymer Creek	507	3	Flows 7	.....	Basal Pamunkey...	Water also at 240 and 464 feet.
Fairport	393¼	1¼	Flows 2	.....	Basal Chesapeake..	Soft, good water.
Fort Monroe.....	907	.....	None.	.....	Potomac?	
Fort Monroe, Chamberlin Hotel.	945	.....	Flows 50	+10	.....do.....	Slightly saline water.
Franklin, 16 wells...	130	.....	Many.	Flow.	Chesapeake	
Gabels Mill.....	226	1¼	Flows 20	+10	Basal Chesapeake..	
Gloucester Court House.	600	.....	None.	.....	Pamunkey?	Stopped at rock stratum.
Homewood, 5 wells.	317	1¼	Flows 30	.....	Basal Chesapeake..	Fine water 54°. Sulphurous water at 270 feet.
	112	1	Fair supply.	+2	Chesapeake	Ferruginous water.
Jamestown	248	3	Flows 2¼	+35	Basal Chesapeake..	Fine water 68°.
King and Queen.....	200	2	Flows 1	.....	Basal Pamunkey?..	
Kinsale.....	235	1¼	5	+15	Basal Chesapeake..	
Lancaster	250	.....	Flows 12	.....	.....do.....	
Do	285?	.....	.....	.....	.....	
Lester Manor, 3 wells.	200	1¼	Flows 12	+8 to +12	Basal Pamunkey?..	
Lewisetta.....	317¼	.....	.....	.....	Basal Chesapeake..	
Little Plymouth	168	2	Flows 2	.....	.....do.....	
Monaskon	255	.....	.....	.....	.....do.....	
Monatico Creek.....	250	1¼	Flows 2	+	.....do.....	
Mount Carmel Church.	190	.....	Flows 1¼	+6	Chesapeake	
Naylors.....	386	1¼	Flows 3	+45	Basal Pamunkey...	Much water at 326 feet.

[a] +, feet above the surface; −, feet below the surface.

Partial list of deep wells—Continued.

Location.	Depth.	Size.	Capacity per minute.	Height to which water rises.	Horizon.	Remarks.
	Feet.	*In.*	*Gallons.*	*Feet.*		
Newcastle	187	1¼	Flows 10	+2	.....	
Newport News	4,600	.....	None.	.....	Chesapeake	
Norfolk	147	6?	Much.	—6	do	Very hard water.
Norfolk, Lambert Point.	610	.....	65	.....	do	Saline water.
Norfolk, Money Point.	562	.....	Much.	+5	do	Ferruginous water.
North End Point	1,172	.....	None.	.....	Potomac	
Oak Springs	400	1¼	Flows 10–12	+6	.....	
Onancock	140	4¼	5	.....	Chesapeake	140–486 feet; no water.
Plum Point, 3 wells	168	1¼	Flows 10–12	+8–12	Basal Chesapeake	
Possums Nose	200	.....	.....	.....	Potomac	
Providence Forge	80	1¼	None.	.....	Chesapeake	Unfinished.
Puritan Bay, 2 wells.	215	1¼	Flows 10–12	+4–6	Basal Chesapeake	
Puritan Bay, 1 well	180	1¼	Flows 10–12	+4–6	.....	
Quantico	350	.....	4–5	Flows.	Basal Potomac	
Ragged Point	225	1¼	1	12	Basal Chesapeake	
Richmond:						
Paper mill	400	.....	Fair.	.....	Granite	Surface contamination.
Sherwood Park	900	.....	None.	.....	do	
Sherwood Park, 1 mile northeast.	250	.....	None.	.....	do	
Ginter's farm	400	.....	Satisfactory.	.....	do	Fine water.
Sandy Point:						
Westmoreland County.	235	1¼	3	+12	Basal Chesapeake	
Fairfax County	560	.....	Satisfactory.	—24	Basal Potomac	No water below 270 feet; rock, 270–560 feet.
Sharps Wharf	235	1¼	Flows 12–35	+24	Basal Chesapeake	
Do	360	.....	.....	.....	Pamunkey	Water also at 240 feet.
Sheppard's warehouse, 2 wells.	160	1¼	Flows 10–15	+6–8	Basal Chesapeake	
Swan Point	+100	.....	.....	.....	Chesapeake	
Virginia Beach	70	.....	Fair supply.	.....	Upper Chesapeake	Ferruginous water.
Walkerton, 2 wells	315	1¼	Flows 5–8	+4–6	Potomac	
Weems	260	.....	.....	.....	Chesapeake	
West Point, 200 wells.	160	1¼	Average 12	Average +2.	Basal Chesapeake	
Whealtons	250	.....	20	.....	Basal Chesapeake?	
White House, 3 wells.	180–230	1¼	1–6	+5–20	Basal Chesapeake	
Williamsburg	876	.....	None.	.....	Potomac	
Do	280	.....	Many.	.....	Basal Chesapeake	Under hard rock stratum.
Windmill Point	430	.....	None.	.....	Near to basal Chesapeake.	To top of rock stratum.
Zuni	161	.....	Flows 2	.....	Chesapeake	

PIEDMONT PLATEAU.

The Piedmont Plateau extends from the Coastal Plain on the east to the foot of the Appalachian Mountains on the west. Its surface is made up mainly of more or less crystalline igneous or metamorphic rocks, but is marked by a number of basins of Triassic shales and sandstones.

Over the greater part of the Piedmont Plateau the uplands are smooth and rounded and the streams flow near their heads in broad, shallow valleys. In their lower courses the streams, especially the larger ones, have formed deep channels, and a strongly rolling topography has been developed. Toward the west the topography merges into that of the Appalachian Mountain belt.

Crystalline rocks.—The crystalline rocks of the Piedmont belt are deeply weathered at the surface and are broken by numerous joints that extend to considerable depths. As in similar regions elsewhere, the weathered upper portion everywhere furnishes supplies for shallow wells. Few deep wells have been drilled, but it is probable that moderate amounts of water would be obtained in a considerable percentage of the wells sunk. The water, however, would be likely in many instances to be rather strongly mineralized and unsuitable for some purposes. Moreover, because of the uncertainty of the presence of joints or other water-bearing fissures in the rock, the occurrence or nonoccurrence of water in a well at a given locality can seldom be predicted.

Triassic rocks.—The Triassic rocks consist of a series of shales and sandstones, with a few coals, etc., occupying basin-like depressions in the Piedmont Plateau. Moderate or small supplies of water are generally obtained by the shallower wells. Deeper wells would probably obtain considerable amounts in many instances, although, as in other Triassic areas, the waters are likely to be mineralized. Strong springs occur along certain of the faults which cut this area, and it is not improbable that flowing waters could be obtained in some localities.

APPALACHIAN MOUNTAIN BELT.

The term Appalachian Mountain belt is used in a broad way to include the entire belt of folded rocks lying between the Piedmont Plateau and the Cumberland and Allegheny plateaus of West Virginia and Pennsylvania. The rocks are of Cambrian, Silurian, and Devonian age, and include quartzites, sandstones, shales, and limestones. Near the eastern limits of the belt, separated from the Piedmont Plateau by only a narrow strip of folded rocks, is the Shenandoah Valley. This valley is underlain by Cambro-Silurian limestones.

The Appalachian Mountain belt is in general thinly inhabited and contains few wells. Springs abound and constitute the main source

of supply of the inhabitants. The quartzites carry very little water in their denser portions, although springs of considerable size sometimes issue from their more porous parts. The springs of the shales are numerous, but are generally small. In the limestone area of the Shenandoah Valley, a region which is relatively thickly inhabited, dependence is placed largely on cisterns, the waters of the limestone being of uncertain occurrence. Near the borders of the limestone area, however, springs occur at some places, and it is probable that deep wells would often procure good supplies at these localities, but as the water sometimes occurs in definite underground channels successful wells would not always be obtained at such places.

The waters of many of the springs of the higher portions of the Appalachian belt are warm, and at a number of places the springs have been developed as resorts. At other springs the waters are bottled and sold for medicinal purposes. The association of these springs with anticlines was long ago pointed out by W. B. Rogers. It is not improbable that here, as in other regions, in some instances the locations of the springs were determined by faults.

CUMBERLAND PLATEAU.

The name Cumberland Plateau is applied to the elevated area of Carboniferous rocks lying northwest of the Appalachian Mountain belt. Only a small part of this area is included in Virginia, and that lies in the extreme western part of the State. The underground water supplies of this region are like those of the portion of the plateau included in Pennsylvania and Maryland. Practically no deep wells have been sunk, but it is probable that such wells if put down would obtain water from some one of the more sandy beds. It might even rise to the surface in synclines or other favorable situations. Springs are fairly numerous, but small.

COMMERCIAL SPRINGS.

During the year 1902 sales of water were reported from 48 springs, including representatives from each of the geologic divisions except the Cumberland Plateau. These are as follows:[a]

* Ætna Lithia Springs, Roanoke, Roanoke County.
* Augusta White Lithia Spring, near Augusta Springs.
* Basic Lithia Spring, Basic City, Augusta County.
* Bear Lithia Springs, near Elkton, Rockingham County.
† Beaufont Lithia Spring, Beaufont, Chesterfield County.
† Bellfont Spring, near Manchester, Chesterfield County.
† Berry Hill Mineral Spring, near Elkwood, Culpeper County.
* Blue Ridge Springs, Botetourt County.
† Buffalo Lithia Springs, Buffalo Lithia Springs, Mecklenburg County.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

† Chase City Mineral Springs, Chase City, Mecklenburg County.
† Como Lithia Spring, East Richmond, Henrico County.
† Coppahaunk Lithia Arsenic Springs, near Waverly, Sussex County.
* Cove Lithia Spring, Wytheville, Wythe County.
* Craig Healing Spring, Vista Craig, Craig County.
* Crockett Arsenic Lithia Spring, Shawsville, Montgomery County.
Diamond Spring, Norfolk County.
† Erup Mineral Spring, near Glen Carlyn, Alexandria County.
† Farmville Lithia Springs, Cumberland County, near Farmville, Prince Edward County.
† Fonticello Lithia Spring, Chesterfield County, near Richmond.
* Golindo Lithia Springs, Weyers Cave, Augusta County.
† Harris Anti-Dyspeptic and Tonic Spring, Burkeville, Nottoway County.
* Healing Springs, Healing Springs, Bath County.
† Houston Lithia Spring, Houston, Halifax County.
† Hume Springs, St. Elmo, Alexandria County.
* Hunter's Pulaski Alum Springs, Walkers Creek, Pulaski County.
† Jeffress Lithia Silica Springs, Jeffress, Mecklenburg County.
* Jordan White Sulphur Spring, Stephenson, Frederick County.
† Lone Jack Spring, Candless Mountain, Campbell County.
† Magee's Chlorinated Lithia Springs, Clarksville, Mecklenburg County.
† Massanetta Springs, Harrisonburg, Rockingham County.
* Montvale Hygeia Spring, Montvale, Bedford County.
* Nye Lithia Springs, Wytheville, Wythe County.
* O'Connell Lithia Spring, near Stribling Springs, Augusta County.
† Otterburn Lithia and Magnesia Springs, Amelia, Amelia County.
† Paeonian Spring, Paeonian Springs, Loudoun County.
† Pontiac (formerly Powhatan) Spring, near Falls Church, Alexandria County.
† Powhatan Lithia and Alum Springs, near Tobaccoville, Powhatan County.
* Rockbridge Alum Springs, Alum Springs, Rockbridge County.
* Rubino Healing Lithia Springs, Healing, Bath County.
* Seawright Magnesian Lithia Spring, near Staunton, Augusta County.
* Seven Springs, near Glade Spring, Washington County.
* Shenandoah Alum Springs, near North Mountain, Shenandoah County.
† Sublett's Lithia Spring, near Danville, Pittsylvania County.
† Swineford's Arsenic Lithia Springs, Osceola, Chesterfield County.
* Virginia Magnesian Alkaline Springs, near Staunton, Augusta County.
* Virginia Waukesha Lithia Springs, Staunton, Augusta County.
* Wallawhatoola Alum Springs, near Millboro Spring, Bath County.
† Wolf Trap Lithia Springs, Wolf Trap Depot, Halifax County.

Of these only the Diamond Springs of Norfolk County appear to be in the Coastal Plain. Of the remainder those marked * are in the Mountain belt, while those marked † are in the piedmont belt. The total output for 1902 was 2,442,398 gallons, having a value of $423,212.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 54–68.
Artesian-well prospects of the Atlantic Coastal Plain region, by N. H. Darton: Bull. U. S. Geol. Survey No. 138, pp. 162–190.

Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, p. 60.

Description of the Fredericksburg quadrangle, Maryland and Virginia, by N. H. Darton: Geol. Atlas U. S., folio 13, U. S. Geol. Survey.

Description of the Nomini quadrangle, Maryland and Virginia, by N. H. Darton: Geol. Atlas U. S., folio 23, U. S. Geol. Survey.

Description of the Washington quadrangle, Maryland, District of Columbia, and Virginia, by N. H. Darton and A. Keith: Geol. Atlas U. S., folio 70, U. S. Geol. Survey.

Description of the Norfolk quadrangle, Virginia and North Carolina, by N. H. Darton: Geol. Atlas U. S., folio 80, U. S. Geol. Survey.

NORTH CAROLINA.

By M. L. Fuller.

In North Carolina only two of the geographic and topographic belts recognized in Virginia are extensively developed. These are the Coastal Plain and the Piedmont Plateau. That part of the Appalachian Mountain belt which consists of folded sedimentary rocks is present only in the extreme western portion of the State. The Piedmont Plateau, however, becomes in this State mountainous as it approaches the former belt and topographically grades more or less imperceptibly into it. The Cumberland Plateau is not represented in the State.

COASTAL PLAIN.[a]

The geology of the Coastal Plain in North Carolina differs from that of Virginia principally in the reappearance of the marine Cretaceous beds, which thicken rapidly and rise to tide-water level and above nearly as far east as Wilmington. The Eocene formation thins somewhat, and in the southern counties lies almost entirely above tide level, on an irregular floor of marine Cretaceous sands and marls.

The Chesapeake beds thin rapidly southward, and lie mostly above tide level in shallow basins on the Eocene or marine Cretaceous.

The Potomac, the most important water-bearing formation of the Coastal Plain region, is best developed along the western border of this region in the counties southwest of the Neuse River—Harnett, Moore, and Richmond. In these counties the Potomac strata are exposed at intervals over a considerable area; and, dipping gently southeastward on the eroded surface of the crystalline rocks, doubtless carry considerable quantities of water. The Potomac formation also reaches the surface over limited areas, both north and south of Roanoke River above Weldon, and there are also outcrops of the formation at intervals between the Roanoke and Neuse rivers, but in this region the exposed areas of the formation are far less extensive than between the

[a] Compiled from notes of J. A. Holmes published in Bull. U. S. Geol. Survey No. 138, 1896, pp. 190-19..

Neuse and the Pedee, and consequently the underground water supplies below the Tertiary marls of the counties between the Neuse and Roanoke will probably prove to be less abundant than in the more southerly counties.

The general geologic structure of the Coastal Plain in North Carolina is indicated in the accompanying section by Professor Holmes, fig. 20.

FIG. 20.—Cross section of the Coastal Plain region in North Carolina, from near Sanford to the coast near Wilmington. A, crystalline schists; B, Potomac sand, arkose, and clays; C, marine Cretaceous sands, marls, etc.; D, Tertiary marls and shell rock (Eocene and Chesapeake); E, Lafayette and overlying Columbia formation. Vertical scale greatly exaggerated.

It is not yet possible to present a review of the water horizons or of the well prospects in the State, but the following partial list of wells shows the results obtained by drilling at a considerable number of points.

Partial list of deep wells in the Coastal Plain region of North Carolina.

Locality.	County.	Depth.	Remarks.
		Feet.	
Elizabeth City, 10 wells	Pasquotank	64	Flow 15 gallons each; water hard and sulphurous.
Edenton	Chowan	340	No water.
Avoca	Bertie	180	Do.
Washington	Beaufort	140	Water not very satisfactory in quality.
Do	do	100	Do.
Do	do	360	No water.
Yatesville	do	215	Flows 50 to 60 gallons.
D. C. Way Lumber Co	do	300	Flows 15 gallons of sulphurous water; water also at 120 feet.
Roper	Washington	50–75	Yields 10 gallons of unsatisfactory water.
Lake Landing	Hyde	205	Pumps 15 gallons of fine water; water also at 85 feet.
Lake Comfort	do	115	Flows; water sulphurous.
Swanquarter	do	340	Flows a good supply of fine water from depth of about 86 feet.
Rose Bay	do	130	Flows good water.
Scranton, 3 wells	do	100, 160, and 195	Satisfactory water.
Middleton	do	212	Flows good water.
Fairfield	do	230	Flows.
Newbern	Craven	350	Pumps good water.
Do	do	50	Do.
Do	do	90	Do.
Springer Lumber Co	Pamlico	90	Pumps very hard water.
Beaufort	Carteret	200	Flows sulphurous water.
Jacksonville, 3 wells	Onslow	160	Do.

Partial list of deep wells in the Coastal Plain region of North Carolina—Continued.

Locality.	County.	Depth.	Remarks.
		Feet.	
Tarboro	Edgecombe	75	Flows 2 gallons.
Do	do	82	Pumps.
Do	do	160	Do.
Do	do	218	Flows.
Greenville	Pitt	200+	Water obtained, but pipe filled with sand.
Wilson Cotton Mills	Wilson	125	Hard water.
Goldsboro	Wayne	266	Quantity and quality satisfactory.
Kinston	Lenoir	115	Pipe filled with quicksand.
Lagrange (5 miles south)	do	57	Flowing well.
Warsaw	Duplin		In progess.
Burgaw	Pender	100	Water to near surface; quantity and quality satisfactory.
Longcreek	do	175	Stopped in quicksand.
Vineland	Columbus	63	Flows 4 gallons.
Do	do	225	Water nearly to surface.
Wilmington	New Hanover	495	Flows 75 gallons; very saline water.
Wilmington, 3 wells	do	84–100	Pump 400 gallons each of good water.
Hammocks	do	400	8-gallon flow of good water from 100 feet (?).

PIEDMONT PLATEAU.

The Piedmont Plateau lies between the Coastal Plain and the folded mountain belt, as in Virginia. The rocks are crystalline (igneous or metamorphic), and are characterized by basins of Triassic shales and sandstones similar to those in Virginia.

The topography is much the same as in Virginia, except that it is more rugged in the western portion next to the mountains. The crystalline rocks are even more weathered than in Virginia and are similarly broken by joints. Water in small to moderate amounts could probably be obtained almost anywhere within this belt, although large supplies are not to be looked for. It would rarely, if ever, rise to the surface, and is likely to be mineralized. The waters of the springs of the belt contain large amounts of mineral matter and are extensively used for medicinal and table purposes.

The Triassic rocks are somewhat similar to those in Virginia, and doubtless carry considerable water in their more porous beds. Very few deep wells, however, have been sunk in the Triassic areas.

APPALACHIAN MOUNTAIN BELT.

As has been indicated, only a part of the Appalachian Mountain belt lies within the State of North Carolina. The rocks represented are more metamorphic than those in the States previously described, and are frequently crystalline or semicrystalline. A few of the less metamorphic rocks also occur. The mountain belt in this State is relatively

inaccessible and very thinly inhabited. The numerous springs which occur throughout the belt form practically the entire source of water supply of the inhabitants.

MINERAL SPRINGS.

The important mineral springs of North Carolina are located on the Piedmont Plateau. Of the 10 springs that report sales of water in 1902 only 1—the Seven Springs of Wayne County—is in the Coastal Plain. The following is a list of these springs:[a]

Alkalithia Spring, Alkalithia Springs, Alexander County.
Barium Rock Spring, Barium Springs, Iredell County.
Jackson Springs, Jackson Springs, Moore County.
Lemon Springs, Lemon Springs Station, Moore County.
Mida Spring, near Charlotte, Mecklenburg County.
Panacea Springs, near Littleton, Warren County.
Park's Spring, Caswell County, near Danville, Va.
Seven Springs, Sevensprings, Wayne County.
Thompson Bromine Arsenic Springs, Crumpler, Ashe County.
Vade Mecum Spring, Vade Mecum, Stokes County.

The total quantity of water sold in 1902 is given as 104,400 gallons, having a value of $18,795.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 74–78.

Artesian-well prospects of the Atlantic Coastal Plain region, by N. H. Darton [North Carolina, by J. A. Holmes]: Bull. U. S. Geol. Survey No. 138, pp. 190–207.

Preliminary list of deep borings in the United States, Pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, pp. 20.

Water resources of the Cowee and Pisgah quadrangles, North Carolina, by H. S. Gale: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, pp. 174–176.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

SOUTH CAROLINA.

By L. C. Glenn.

SUBDIVISIONS.

South Carolina is divided by a line running northeastward from Augusta, Ga., through Columbia, Camden, and Cheraw, S. C., into a Coastal Plain portion to the southeast and a Piedmont Plateau portion to the northwest. The Coastal Plain region is somewhat the larger of the two divisions and consists geologically of interstratified beds of sand, clay, and marl of Cretaceous or later age that are as yet mostly unconsolidated. The Piedmont Plateau region consists geologically of crystalline rocks whose exact age is unknown, although they are thought to be largely Archean or Algonkian. Because of this difference in their geology the water supplies and water-supply problems of the two sections of the State differ widely in their nature. Each section will be considered separately.

The climatic factors affecting the water supplies are simple and may be briefly stated. The annual rainfall varies somewhat from year to year, but averages about 50 inches and is almost uniformly distributed over the State. Autumn is the dryest of the seasons, receiving 2 or 3 inches less than its normal proportion of the rainfall, and in consequence streams are usually lowest in the late fall. Winter receives 2 or 3 inches more than its proportion. The streams of the Coastal Plain are never frozen over. During severe winters ice may occasionally form on streams in the inner part of the Piedmont region, but it lasts only a few days at a time and never becomes thick enough to interfere with the utilization of the streams for water power.

GEOLOGY AND WATER SUPPLY.

PIEDMONT PLATEAU.

GENERAL FEATURES.

Character.—Viewed broadly the Piedmont Plateau is essentially a plane surface with an average elevation along its outer or southeastern edge of 500 feet. It rises gently to the northwest to an average elevation of 1,000 feet along its inner edge. Beneath this general surface the main streams which flow southeastward have incised their courses 50 to 150 feet, and with their many tributaries have sculptured

it into a gently rolling plateau that breaks into hills near the main drainage ways.

Rocks.—The rocks of the Piedmont Plateau consist of highly metamorphosed gneisses and schists, cut by granites and later intersected by many dikes, chiefly of diabase and presumably of Newark age. The gneisses and schists are regarded as pre-Cambrian in age. They have suffered such profound and repeated metamorphism that in very many cases their original character has been lost. Original bedding planes, if any ever existed, have been obliterated and planes of schistosity have been developed that have prevailingly a northeast-southwest strike and steep dips that range between southeast and northwest. In a few places narrow broken belts of crystalline limestone or of metamorphosed conglomerates indicate original sedimentary beds.

The granites are prevailingly coarsely crystalline to porphyritic, though some areas are of fine and uniform grain. They were intruded at various periods, all of which were probably pre-Cambrian, and have since been exposed at the surface by long and profound erosion, for it seems highly probable that the Piedmont Plateau has been a land surface since early Paleozoic time.

Residual soil mantle.—During all this time the disintegration and weathering of the crystalline rocks of the plateau has been in progress. During most of the time the solid rocks have been covered with a blanket of weathered material, which has at certain periods of uplift been largely removed to furnish material to build the Coastal Plain. At present a blanket of disintegrated material 50 to 150 feet thick overlies the solid rock over practically all of the Piedmont region. Much of this disintegrated material, especially near the surface, is a very fine-grained red clay, that makes the Piedmont streams a muddy red or yellow color.

WATER SUPPLIES OF PIEDMONT PLATEAU.

Effect of residual mantle.—The residual mantle plays an important rôle in relation to the water supply of the Piedmont region, for much of the rainfall is absorbed by it and held to be fed out gradually to springs and streams, thus making the stream flow more uniform than if the undisintegrated crystallines reached nearly to the surface. The main streams of the region have cut down through this blanket of disintegrated material to the solid rock beneath, which often shows in exposed ledges along their courses. Many of their tributaries have cut narrow valleys far back into the interstream area.

Springs.—Along the sides of the valleys, large and small, are found many unfailing springs, whose waters are usually free from mineral impurities of any kind. In the early settlement of the Piedmont region of South Carolina these springs were universally used for household water supplies. Wells and cisterns were unknown. The

pioneer built his house near some bold spring, very often selecting a site on the hill slope or down in the small valley itself. Springs thus determined the location of the homes of the first settlers and for years continued to furnish practically the only water supply. They are used in very many cases to-day, and, in spite of the clearing of the land and the comparatively thick settlement of the country, have not failed or become polluted by man's presence, but they are still safe and satisfactory sources of domestic water supply.

There are a number of well-known mineral springs in the Piedmont region, at some of which hotels with good accommodations have long enjoyed wide popularity as summer resorts. The waters of these springs generally contain sulphates and carbonates of calcium, magnesium, sodium, and potassium. Some contain lithia and some are chalybeate.

The following springs,[a] all located within the Piedmont Plateau, reported shipments in 1902:

Buffalo Lick Springs, near Carlisle, Union County.
Chick Springs, near Taylor Station, Greenville County.
Cokesbury Mineral Spring, Cokesbury, Greenwood County.
Garrett Mineral Spring, Spartanburg, Spartanburg County.
Glowing Spring, near Calhoun Falls, Abbeville County.
Harris Lithia Spring, Harris Springs, Laurens County.
Rives Mineral Spring, Lancaster, Lancaster County.
West Springs, West Springs, Union County.
White Stone Lithia Spring, Spartanburg, Spartanburg County.

The aggregate amount of water sold is stated as 259,706 gallons, with a value of $76,525.

Open wells.—With increasing wealth and culture there came a demand for better building sites, and houses began to be erected back on the nearly level interstream uplands remote from springs, and the digging of open wells was begun. These open wells furnish the greater part of the water supply of the Piedmont region to-day. In some cases pure soft water is obtained before solid rock has been reached; in others water is obtained just on top of the solid rock, while in still others it is occasionally necessary to go into the solid rock some distance to a water-bearing seam. The wells of the Piedmont region range from 40 to 70 feet in depth, and they usually have from 5 to 10 feet of water, and rarely fail during dry seasons. The disintegrated material through which they are dug is not firm enough to be left unwalled, so that a curbing, usually of loose stone, is put in. In many cases not enough attention is paid to sanitary precautions, but as the water entering the well under the usual circumstances filters down through a considerable thickness of sand and clay, it is largely though not entirely protected from contamination. Occasionally one finds a

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

bored well of 8 or 10 inches in diameter, though the dug well is far more common. These bored wells differ from the dug ones chiefly by being cheaper to sink, but they are more difficult to clean out.

Deep wells.—Aside from the streams of the region the only possible source for considerable water supplies is the subsurface waters. The presence of granites and crumpled gneisses and schists in the region precludes the hope of securing deep artesian waters, for the structure of such rocks is unfavorable to artesian conditions.

Some Piedmont towns, however, moved by the idea that they could get artesian waters if they only bored deep enough have drilled wells several hundred feet into the crystalline rock, and, except in very few cases, have been rewarded with supplies of water that have risen to a height coinciding with the level of the ground-water surface in the rocks around the well, but such supplies are not artesian. The rocks of the region are traversed by seams and fissures, which everywhere below the ground-water level are filled with water. The deeply drilled hole has cut across enough such fissures to obtain a large supply of water for the pumps, yet this water is derived, not from a great depth nor from a long distance, but from the great body of ground water near the surface and immediately around the well. If the fissures in the solid rock are very numerous, the area supplying the water is an inverted cone whose apex is the lowest point of entry in the bore hole and whose base is a large circular area of the ground-water surface around the well mouth, and only one, two, or three score feet beneath the surface of the town, with its innumerable sources of pollution of every kind. If the well is supplied by only one fissure or by a very few fissures, they must be correspondingly larger and furnish more direct and easy lines of flow to the well. They may extend almost uninterrupted nearly up to the surface and furnish a direct channel for surface waters to enter the well.

The amount of water that can be pumped from such wells is usually large and analyses made when the well is first completed have shown a good, pure, clear, and usually soft water, well adapted to almost any purpose. But while at first such deep wells may be protected from contamination by the surface-soil layer, which acts as a filter, and the water may be pure and wholesome, yet they are very apt sooner or later to become contaminated. Constant pumping from them soon causes the indrafts supplying the water to open better channels through the fissures and allows more direct ingress of waters from the surface. These channels sooner or later are able to carry surface contamination directly into the well. Such deep wells are therefore at best open to grave suspicion and constantly need careful watching. This need is all the more necessary because of the fancied security given by the very favorable analysis of the water when first used. Such careful watching will usually result in the condemnation and

closing of the well in a few years, especially if the town be of considerable size, so that there is furnished to the soil a large amount of contaminating organic material. A well of this kind drilled over 2,000 feet deep in Atlanta, Ga., some years ago, which at first furnished a large amount of acceptable water, was ordered closed by the board of health after a few years' use because of sewage pollution.

At Chester the first deep well sunk into the crystalline rocks failed to strike a single fissure, but was drilled perfectly dry 500 or 600 feet into a solid mass of porphyritic diorite. It was abandoned and a second attempt was made in another part of the town that was successful in striking a water-bearing fissure at 404 feet. A failure may at any time result from deep drilling in the crystallines, though as a general rule fissures are abundant enough to make it reasonably certain that water will be obtained in such wells at a reasonable depth.

Another source of water supply adequate for manufacturing plants or large institutions where only a few hundred thousand gallons are used daily, but usually not deemed sufficient for city supplies, is coming into use in the Piedmont region. It consists of tube wells, which are sunk usually in groups through the decomposed surface material down to solid rock, and which derive their supplies from water circulating slowly just on top of this rock. These wells are usually only a few inches in diameter and vary in depth with the depth of the surface disintegration, ranging from 30 to 80 feet in most cases. They are sunk along or near the lowest line of a natural valley or depressed area toward which a considerable surface area slopes, the larger the basin's extent, other things being equal, the larger the probable supply. Much of the rain falling in the basin percolates down through the soil and moves slowly along on the bed-rock surface, the slope of which usually coincides in the main with that of the soil surface above it. In some cases the clay soil near the surface may be so close grained as to act as an impervious covering for the water in the partly disintegrated and loosened rock beneath, so that wells sunk in this manner may be truly artesian—that is, they may have a natural flow caused by the pressure of the water confined beneath an impervious layer. The distance in this case from which the water comes is of course limited to the basin in which the well is sunk. It is a local artesian basin formed under exceptional conditions.

Such supplies of water have been found uniformly satisfactory. This result has of course been attained by selecting basins free from sources of contamination. The continued purity of such water will of course depend on the vigilance exercised in keeping the basin free from pollution. As such basins are ordinarily small this is not a difficult task. Several such wells in a group are usually connected and pumped together, and several such groups, if a sufficient supply is obtainable

within a small area, would be sufficient to furnish with water a town of some size, or to aid materially in supplying a large city.

In York, Chester, Union, and Abbeville counties there are considerable areas of diabase or diorite that on weathering produce a close-grained clay soil that is abundantly charged with lime and magnesia. The springs and wells of these areas are accordingly of hard water. The use of cisterns is more necessary here than anywhere else in the Piedmont region, and yet they are the exception rather than the rule.

Streams.—Where larger supplies of water for manufacturing plants or town corporations are desired, resort is had in most instances to streams, and a pumping plant is installed to lift the water to a reservoir or standpipe. The streams of the Piedmont region are never perfectly clear except at their headwaters, among the mountain spurs that project from the Appalachians out upon the inner edge of the Piedmont area. The fine red clay soil, so characteristic of the deeply-weathered Piedmont surface, is washed into the streams in great quantities by every rain, and the waters become exceedingly muddy. So finely divided are some of these clay particles that they remain suspended indefinitely, and even with prolonged settling it is difficult or impossible to get the water perfectly clear. The excessive muddiness disappears very soon after the passage of a flood, but even in their lowest stages the Piedmont streams do not become perfectly clear. When they are used for city water supply, ample settling basins must be provided or a filtration plant must be installed. The clay is suspended in the water in particles so fine that it can be removed with difficulty even by filtration.

The most inviting sites for the location of towns in the Piedmont region have been the comparatively level interstream areas that form the divides between the main streams, and, as a rule, the principal towns of the region are both remote from and at a considerable elevation above the larger streams, thus occupying situations that greatly increase the cost of water supplies derived from such sources.

Furthermore, with the rapid growth of large cotton mills along these Piedmont streams, each with its attendant mill village in which the sanitation and the sewerage system are usually not what they should be, the problem of obtaining unpolluted water supplies from the streams of this region will constantly become more difficult.

With the growth of larger cities in the Piedmont area, however, other sources must in time become inadequate and the large streams must furnish the water supplies. Means must then be taken to provide sufficient settling area or adequate filter plants as well as to guard the watersheds of the catchment area from organic pollution. These water-supply problems are not different from those other communities have to face except, perhaps, as to the almost permanent suspen-

sion of the very fine clay particles, and can be successfully solved here just as they have been elsewhere.

COASTAL PLAIN.

The Coastal Plain attains a width of nearly 150 miles. The average elevation of its inner edge where it overlaps the Piedmont crystallines is about 500 feet. The slope of the surface from the inner edge toward the coast is at first rather steep, so that 30 miles from its inner edge the average elevation has decreased to less than 200 feet. From this line to the sea the surface slope is very gentle. Much of the outer part of the Coastal Plain is low and swampy and the rivers crossing the region are usually fringed with swamps that are in places 5 to 10 miles wide.

The inner, more elevated portion of the Coastal Plain is deeply trenched by the rivers that enter it from the Piedmont region, and much of its surface has been cut into hills by the tributary streams that drain it. An inner belt of these hills is known as the *sand hill* belt; an outer interrupted belt that is in places more broken and hilly than the preceding one is known as the *red hill* belt.

GEOLOGY.

Crystalline floor.—Along the outer edge of the Piedmont Plateau the surface of the crystalline rocks dips southeastward and passes beneath the overlapping sands and clays of the Coastal Plain. From well records something has been learned of the depth of the crystalline floor beneath the surface of some parts of the Coastal Plain; but much more information is desirable concerning its depth, especially beneath the central and southwestern parts. At Aiken a boring, after passing through 465 feet of sands and clays, reached granite at 62 feet above sea level. At Florence 608 feet of Coastal Plain sediments overlie the rocks of the Newark formation, which were reached at 473 feet below sea level. At Marion a boring that passed through 700 feet of sands and clays entered crystalline schists 632 feet below sea level. At Wilmington, N. C., a well started only a few feet above tide entered granite at a depth of 1,109 feet. At Orangeburg a well 1,160 feet deep had not reached the crystallines, but was probably not far above them. A well at Charleston 2,050 feet deep and one at Beaufort 1,640 feet deep failed to reach the underlying crystallines.

General character of deposits.—The Coastal Plain formations consist of fine gravels, sands, clays, marls, and an occasional soft limestone. The dip of the lower members is southeastward at a rate somewhat greater than the surface slope. The higher members, however, thicken seaward until the youngest members, or those at the top, dip at the same rate as the surface.

Potomac formation.—The oldest of these members is the Potomac. It lies immediately upon the crystallines, and along its outcropping inner edge consists of at least 400 or 500 feet of variegated sands and

clays. Much of the sand is coarse and cross-bedded, and usually contains a considerable amount of arkose. The clay is in very irregular lenticular masses embedded in the sands and does not form continuous and persistent strata. These sands and clays outcrop in the sand hills and in part of the red hills along the inner edge of the Coastal Plain in a belt 5 to 10 or more miles wide, where they receive the supplies of water that they carry seaward with them beneath the later members of the Coastal Plain series. These Potomac sands and clays are water-bearers under very much, if not all, of the Coastal Plain; but very little is known as to their exact depth beneath the surface in much of the region. A 1,160-foot well at Orangeburg had probably reached nearly to their base. At Florence they extend from 200 or 300 feet to 607 feet. At Charleston the 2,050-foot well probably stopped in their upper portion. It is probable that the 1,640-foot well at the naval station at Port Royal had just about reached their top layers, and it is likely that a supply of good water might have been obtained in these Potomac sands within the next few hundred feet had the well not been abandoned where it was. The water found in the deeper-lying portions of the Potomac under the outer part of the Coastal Plain may, however, be found charged more or less with mineral matter, although the water from the deep wells at Charleston is reported to be of excellent quality and furnishes the city's supply.

Marine Cretaceous beds.—The marine Cretaceous is the next younger formation. It consists of dark, unctuous, fine-grained clays, locally known as fuller's earth, and often described by the drillers as soapstone, interbedded with fine, light-colored micaceous sands. The clays contain abundantly disseminated iron pyrite that readily decomposes and gives rise by further reaction to alum, so that open wells and springs in these clays are sometimes very astringent. These Cretaceous clays outcrop only in the eastern part of the State. They do not form the general surface even here, but are overlain by a thin mantle of younger deposits, and are revealed only in stream cuttings along the Pedee and its tributaries. The best exposures are in Darlington and Florence counties. West of Lynches River the marine Cretaceous is not known to outcrop at the surface. There the Eocene rests directly on the Potomac.

From its surface exposures in the eastern part of the State the marine Cretaceous dips southeastward beneath later deposits, and is reached or passed through in the deeper wells of that region. It extends from about 600 to about 1,900 feet in the Charleston wells. It was passed through in the Orangeburg well, its top being about 252 feet from the surface, and its bottom being indeterminate from the record obtained. The Port Royal well from 700 or 800 to about 1,600 feet is in the marine Cretaceous. Well records show that it consists of sands, marls, and dark clays, the latter sometimes described as very tough and sticky to drill. The layers of sand occupy no definite horizon. They are usually

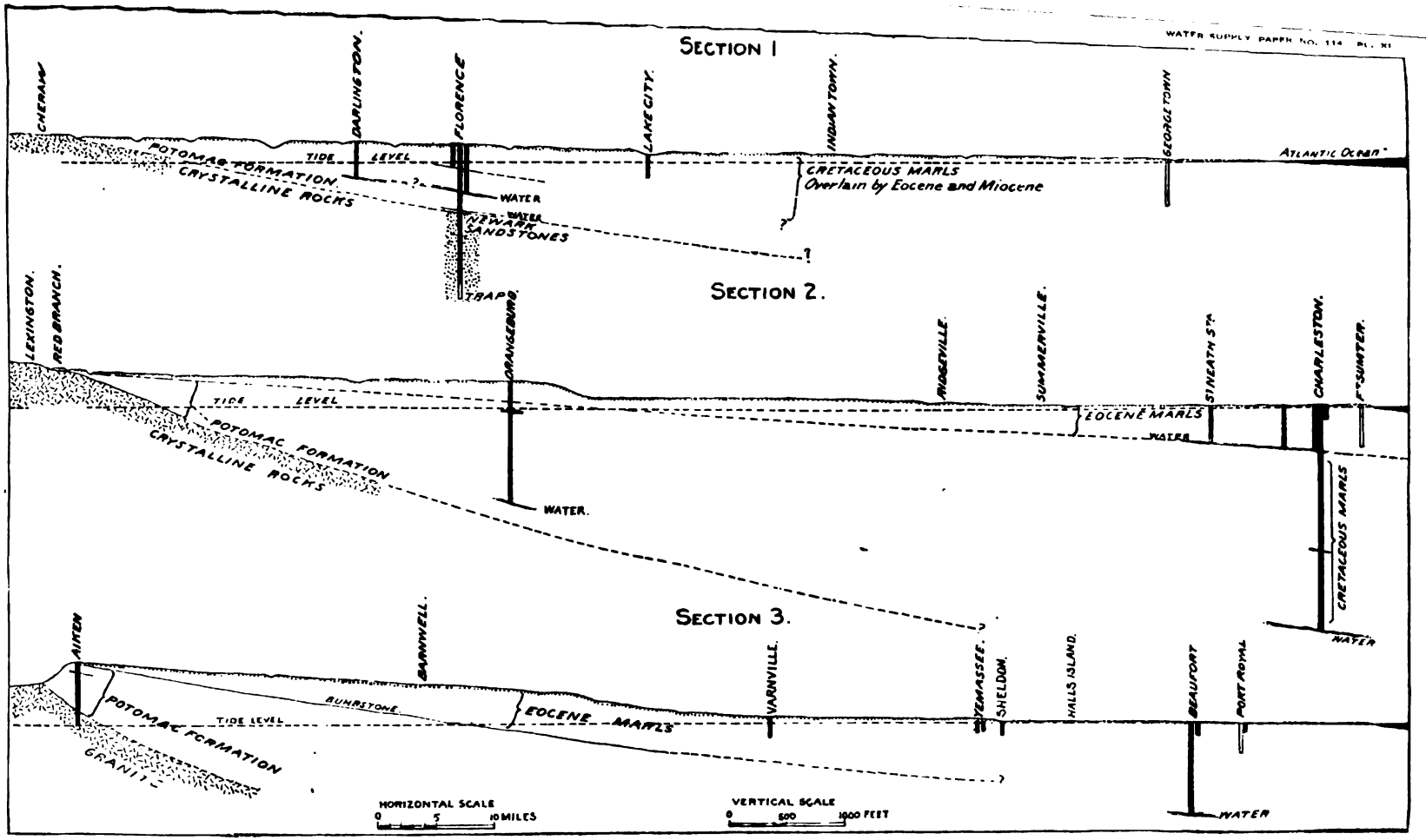
water-bearing, but the water is often charged with sulphur or iron or is brackish or salt. No persistent horizon of potable water is known in this series. Some of the sandy strata may, however, locally contain good water, and careful tests for quantity and quality of water should be made at any promising horizon.

Eocene deposits.—The Eocene overlies the Cretaceous. In the eastern part of the State, where the Cretaceous is exposed in stream cuttings, a few thin, isolated patches of Eocene are found resting in depressions in the Cretaceous surface. West of Lynches River the Eocene rests directly on the Potomac, and in Orangeburg, Lexington, and Aiken counties numerous exposures of it occur. At the base it consists of fine, light-colored siliceous clay, breaking with conchoidal fracture, and overlain by a silicified mass of shells and casts—the Buhrstone. Above it are soft gray to white pulverulent, calcareous marls, whose lower part is known as the Santee marls, and whose upper part is the Ashley and Cooper marls. They may be grouped together here. These Eocene strata are probably 500 feet thick at Charleston and occupy a basin called the Charleston basin, delimited to the northeast by the marine Cretaceous strata, which come to the surface in the Pedee region, but are of unknown extent to the southwest in Georgia, though they rise considerably in Barnwell County.

The Buhrstone division of the Eocene is more or less cavernous and is generally water bearing. The waters, as might be expected, are more or less hard. They are reached at Charleston at about 400 to 500 feet from the surface. At Orangeburg the base of these rocks is probably about 252 feet from the surface. In Bamberg, Barnwell, Colleton, and Hampton counties they seem to be widespread water bearers and are reached at depths of about 100 feet in upper Barnwell, but dip toward the coast so that there they are found at 500 to 700 feet from the surface. The basal Eocene is therefore very generally water bearing and lies at moderate depths beneath that large portion of the Coastal Plain in which the Eocene occurs. No definite water-bearing horizons are known in the overlying Eocene marls. Open wells and springs in these upper beds furnish hard water.

Miocene marl.—A thin stratum of late Miocene shell marl rests in many places on the eroded surface of either the Eocene or, in the Pedee region, the marine Cretaceous. It is not usually widely continuous and is not important as a water-bearing horizon. Open wells sunk to it yield hard water. It rarely outcrops, and so produces but few springs.

Lafayette and Columbia sands.—Along the inner and more elevated red hill and sand hill portion of the Coastal Plain there may be discriminated in most cases two thin formations of sand that blanketwise overlie all of the older formations. The older one is usually a hardened, cross-bedded sand, often carrying considerable clay and near the rivers, as they enter the Coastal Plain, contains rounded pebbles



SECTIONS IN EASTERN SOUTH CAROLINA.

and cobbles. It is regarded as of Lafayette age. Where it overlaps on the Potomac sands and clays it is in many places very difficult to determine the contact line so very similar are their materials, the Lafayette being derived in such cases from the underlying Potomac by a slight reworking. These Lafayette sands and clays are usually red in color. In Columbia they are homogenous, structureless, and bright red. In many places they are mottled red and light gray. They form much of the surface in the "red hill" belt. In the middle and outer half of the Coastal Plain the Lafayette has not been discriminated. If ever present in the outermost part, just near the present coast line, it has very probably been removed by erosion, for the post-Pliocene rests on rounded phosphate nodules that cover the surface of the Eocene or Miocene marls from which they were torn by the waves.

The younger of the two blanketing formations is a light-colored, soft, clean-washed, barren sand that forms the surface of most of the Coastal Plain, including the sand hills. In the middle and outer part of the Coastal Plain it is usually mixed with enough clay to form a loam. In thickness it ranges from a few feet up to perhaps 50 feet in some places near the coast. It is regarded as of Columbia age, but such distinctions as high-level and low-level or fluvial and interfluvial seem inapplicable to it. Its relation to the post-Pliocene deposits indicates that the portion near the coast, at least, is of late Columbia age.

The post-Pliocene, which comes between the Lafayette and the Columbia, is found in places along or in a few miles of the coast. It is a thin stratum of sand and shells and is of no special importance as a water bearer.

WELLS.

The following tables present a comprehensive summary of the results of numerous wells bored in the Coastal Plain of South Carolina. Since the list was made a considerable number of new wells have been drilled, but the present table is nevertheless fairly representative:

Partial list of deep wells in South Carolina.[a]

Locality.	Depth.	Diameter.	Capacity per minute.	Height of water.[b]	Remarks.
	Feet.	*Inches.*	*Gallons.*	*Feet.*	
Abbeville	520	.....	Many.	− 3	In ancient crystallines.
Aiken	568	8–6	50	−170	In granite; water also at 543 feet.
Bamberg:					
30 wells	65-100	.....	.....	.....	In buhrstone.
5 wells	470	2	40	+ 15	In Potomac sands.
	495	2	35	+ 20	
	520	2	35	+ 12	
	555	1½	40	+ 30	

[a] Darton, N. H., Artesian-well prospects in the Atlantic Coastal Plain region: Bull. U. S. Geol. Survey, No. 138, pp. 210–211; also records collected by the writer.

[b] +, feet above surface; −, feet below surface.

Partial list of deep wells in South Carolina—Continued.

Locality.	Depth.	Diameter.	Capacity per minute.	Height of water.	Remarks.
	Feet.	*Inches.*	*Gallons.*	*Feet.*	
Barnwell					
Beaufort:					
Coosaw Company	800				
Water works	120	10	Many.	Does not flow.	
Blacksville	120				
Bluffton. (See Mays River.)					
Camden, 2 wells	618, 625			−20	Water fine. Granite below 82 feet.
Charleston, 6 wells	1260–2000	2½–6	170–800	+ 4 +25	Saline water.
Charleston, 9 wells	323–475				
Chester	500	8			Perfectly dry hole. In diorite.
Do	404?	8	Many.	Does not flow.	In diorite. Depth also given as 372 feet.
Clyde	152				In Potomac sands.
Connors	630 +	6–2			Drilling.
Conway, several	210–240		30	Flows.	Some sulphur.
Darlington	327		30	To surface.	In Potomac formation.
Cotton factory	280	2	10	Flows.	Water from 212 feet.
Denmark	450			Pumped.	Water from 150 feet.
Estill	850			Flows.	
Eutawville	350		Few.	Flows.	
Do	100	2	Many.	Pumped.	
Florence, city works	1,215	10—8	100	− 20	608 to 1,335 feet in Newark sandstone; waters also at 600 and 800 feet.
Do	182			− 24	
Florence, Ice works	200		Many.		Fine water.
Florence, Machine shop	420	Small.	Many.		Do.
Fort Fremont	429				
Fort Motte	141				Abandoned in quicksand.
Grahamville, 2 wells	121	6	170	Flows.	Another well is 164 feet deep.
Do	220	2	Few now.		Water at 170 feet.
Do	220	4	Few now.	Flow.	Hard water, water at 170 feet.
Do	350	4	Few now.	Flow.	Hard water; water at 250 feet.
Georgetown	570		50–60	+10	
Georgetown, 10 wells	65–74	2	Many.	− 4	8 feet of water.
Green Pond	503	3	1	Flows.	Temp. 70° F.
Greenwood	400	8	4	− 4	In ancient crystallines.
Halls Island, Donner Bros	120	6	150	+20 above high water.	Sulphurous water.
Hampton	583	6	Many.	− 9	Soft, irony water.
Do	186			− 3	
Do	46		1 in. stream	+ 4	Irony water.
Do	800?			Does not flow.	
Hartsville, 8 wells	228–240			− 8	In Potomac sands.
Jacksonboro	420	3	4	Flows.	Temp. 72° F.
Johns Island	500	6	11	Flows.	Temp. 70° F.
Kingstree, 3 wells	320	2	Many.	Flows.	Fine water.
Lake City, 10 wells	160–320	3 and 2	7–15	+15	
Manning	375	2	2		Soft.
Marion	1,244	8–9	4	Flows.	Small flow at 700 feet on top of crystallines.
Moncks Corner	179	2	35	−14	16–148 feet in line with flint rock below.

Partial list of deep wells in South Carolina—Continued.

Locality.	Depth.	Diameter.	Capacity per minute.	Height of water.	Remarks.
	Feet.	*Inches.*	*Gallons.*	*Feet.*	
Moncks Corner, 8 miles distant.	175	2	15	Flows.	
Mays River, Bluffton	165	.....	Many.	.....	
Mays River, Capt. T. R. Hayward's place.	800	.....	Fair.	−1	Very sulphurous water.
Mays River, Col. J. H. Estill's place.	190	.....	Many.	.....	Sulphurous water.
Mays River, Col. J. H. Estill's plantation, 4 wells.	360	.....	Many.	Flows.	Fine water.
Mays River, Snyder & Mittle's sawmill.	106	.....	Many.	Flows.	Do.
Newberry	285	.....	.....	Nearly to surface.	In granite.
Oakley Depot	299	2	Many.	Does not flow.	Fine water.
Orangeburg, 4 wells	1,160	.....	Many.	−48	Much water at 250 feet.
Ousley	380	.....	Not any.	.....	In Potomac sands.
Palmetto	346	2	6	Nearly to surface.	
Peeples	853	6	100	Flows.	Temp., 76° F.
Port Royal Naval Station	255	6	Very few.	Does not flow.	Water very impure.
Port Royal Naval Station, 3 wells.	60	5 and 2	Many.	−12-16	Water hard and saline.
Port Royal Naval Station, 2 wells.	95-98	6	125	Pumped.	Good water.
Do	1,640	15-4	.....	.....	Abandoned in Cretaceous clays.
Rowesville	185	3	.....	−6	Hard water.
St. Matthews, 5 wells	75-135	3	.....	Do not flow.	Excellent water.
Scranton	170	2	.....	Flows.	
Seabrook	120	6	150	+12	A little H_2S.
Shelden	152	3	Many.	Does not flow.	On high land.
Sullivans Island, Fort Moultrie.	1,308	12-3	10	Flows.	Temp., 89° F. Contains iron and soda.
Sumter	128	2	2	Flows.	Soft water.
Swansea	100?	.....	.....	.....	
Union	300+	.....	.....	.....	Drilling. In granite.
Varnsville	988?	6	Many.	−17	
Walterboro	490	6	Many.	−30	Soft water.
Wedgefield	580	3-2	.....	−90	Not used.
Williston, L. Green	130	3	5	.....	
Yemassee, G. G. Martin	90	4½	Many.	Flows to +13.	Sulphurous water.
Yemassee, J. B. Gregorie, 8 wells.	85-150	6	Many.	+8	Sulphurous water; flow decreasing.

SUMMARY OF COASTAL PLAIN SUPPLIES.

Shallow wells.—The shallow wells of the Coastal Plain are sunk in the surficial Lafayette and Columbia formations. These wells are usually not over 20 or 30 feet deep. Many, indeed, are from 8 to 12 feet deep, and in wet weather many of them are entirely full of water. Such surface water is as a rule impure and unwholesome, especially if the wells be open. Driven wells are now largely taking the place of

open wells. A 2-inch pipe tipped by a sharp-pointed strainer section is driven from 15 to 30 feet, and a small suction pump is attached to the upper end. Such wells are quickly, easily, and cheaply driven, and do not permit surface waters to trickle down directly from the surface, as do the open wells. Their waters are more wholesome than those of open wells, but their general use will not solve the pure-water problem for the Coastal Plain.

Deep wells.—Many farmers are sinking artesian wells of small diameter and moderate depths to the upper part of the Potomac beds in the inner half of the Coastal Plain, while on the outer half wells are bored deeper with somewhat less certainty of getting good water from the lower Eocene. Unfortunately, very few records that give much information as to the age or kind of beds passed through have been kept by the drillers or owners, so that our knowledge of the underground waters of the region leaves much still to be desired. Experience, however, has proved that in many parts of the Coastal Plain the chances for obtaining supplies of deep water that will rise nearly to or just above the surface are excellent. In other parts, especially very near the coast, the problem is more uncertain because of the great depth of the water-bearing strata and the greater risk of finding the water too highly impregnated with various mineral matters to be usable. Numerous good wells, however, have been drilled near the coast, and drillers in this region should carefully test every water-bearing sand of any promise as they go down.

The use of artesian water has greatly improved the health conditions on the Coastal Plain. Not only has typhoid fever been banished, but of greater importance, because of its former more general prevalence, malaria has been practically banished also, despite the presence of mosquitoes.

Streams.—The streams of the flatter portions of the Coastal Plain are dark wine-colored from the presence of organic matter. Those in the sand hills are usually pure and clear and may be used for bleaching or for any other similarly exacting purpose for which a very pure, clear water supply is necessary. The sand hills yield their underground waters very gradually and regularly to the streams, so that stream discharge in this region is very uniform.

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GEORGIA.

By S. W. McCallie.

Georgia may be divided into three great provinces—the Coastal Plain, the Piedmont Plateau, and the Appalachian or Paleozoic area—each of which represents a great time division of geologic history.

COASTAL PLAIN.

The Coastal Plain includes that part of the State lying south of an irregular line connecting Augusta, Macon, and Columbus, and comprises more than one-half of the entire State. In this region the rocks are Cretaceous and Tertiary clays, sands, and soft limestones, having a general dip southward of only a few feet to the mile. The sands and limestones usually furnish copious supplies of water, which in some instances has sufficient head to be used for irrigation purposes and to operate machinery. The waters from the Cretaceous beds are usually soft, but those from the Tertiary are frequently hard and unsatisfactory for many purposes.

In addition to the underlying Cretaceous and Tertiary formations two surficial formations—the Lafayette and the Columbia—are of especial importance in connection with the water supply of shallow wells. These formations consist of clays and sands, and cover more or less completely the entire Coastal Plain. The Lafayette, the older of the two, lies unconformably on the Cretaceous or Tertiary rocks. It consists of orange and vari-colored sands and clays with local beds of gravel. Overlying the Lafayette is the Columbia formation, which is made up almost entirely of rather fine-grained sand, and in places attains a thickness of many feet, but more often is much thinner, or is entirely wanting. These two surficial deposits are the main sources of the water supplying the shallow wells throughout the Coastal Plain, and they also govern the amount of rainfall taken up by the underlying Cretaceous and Tertiary sands and limestones. Where the Lafayette formation consists largely of clay it forms an impervious water-bearing stratum which to some extent prevents rainwater from penetrating the underlying Cretaceous or Tertiary deposits. On the

other hand, the Columbia sands absorb a large percentage of the rainfall, which is retained until taken up by the underlying deposits. These surficial formations either increase or decrease the water supply in deep wells according as they take up little or much of the rainfall.

PIEDMONT AREA.

The Piedmont Plateau, or crystalline area, embraces all of that part of the State lying north of the Coastal Plain with the exception of the greater part of ten counties in the northwestern portion.

This region is an old eroded land surface, formed of highly metamorphosed igneous and sedimentary rocks, which are frequently weathered to considerable depths. The prevailing rocks are slates, schists, gneisses, and granites, none of which can be considered water-bearers of any great promise. The crystalline area is noted for the numerous small springs that are rather evenly distributed throughout it. There are a few large springs, but they are rare and are usually due probably to the presence of faults rather than to any special water-bearing strata. The deep weathering of the rocks is favorable to a copious supply of water for shallow wells. Nearly all of the small towns are supplied by such wells, which, except during an extremely dry season, furnish an abundant supply of what is generally supposed to be very wholesome water. Deep wells have been drilled by some of the towns, but in the majority of cases the amount of water secured has been inadequate to supply the demand. Furthermore, the geologic structure of the crystalline area is such that water obtained from deep borings is likely to become contaminated sooner or later from surface drainage, especially where there is little or no sandy soils to act as a filter, and where the upturned edges of the rocks dip at a high angle.

APPALACHIAN OR PALEOZOIC AREA.

The Paleozoic area comprises the greater part of ten counties in the extreme northwestern part of the State. The rocks of this region are limestones, shales, and sandstones, thrown into a number of long parallel anticlinal and synclinal folds. The anticlinal folds in many cases have been decapitated and are now replaced by valleys of erosion, while the synclines form the intervening ridges or mountains. These structural conditions are usually unfavorable for flowing wells, but at the same time they materially allow the rainfall to be rapidly absorbed by the upturned edges of the strata. They also explain the distribution of the numerous springs.

The water-bearing strata of the Paleozoic area are the limestones and the sandstones. The limestones, from which most of the underground water is obtained, are usually heavy bedded and compact. The water contained in them frequently occurs in deep fissures or channels as running streams of considerable size.

When these strata outcrop such streams give rise to huge springs, which furnish large volumes of water, and which often occur throughout the Paleozoic area. The largest of these springs are generally found along fault lines or near the contact of limestones with impervious shales. The water from these large springs often becomes muddy after a heavy rainfall, showing that the underground stream which supplies them with water has direct connection with limesinks or other open cavities on the surface. Such springs are also more or less affected by droughts, and have been known to entirely cease flowing during an extremely dry season.

The sandstones of the Paleozoic area which are here spoken of as water-bearing strata are confined chiefly to Sand and Lookout mountains. At several points on these mountains the bore holes put down in prospecting for coal have furnished rather copious supplies of water. The numerous coal mines located on these mountains also demonstrate that the sandstones are water carriers of considerable importance. In northwest Georgia are also very favorable conditions for shallow wells. The residual clays are generally of such thickness as to retain a high percentage of the rainfall within a short distance of the surface and supply shallow wells with ample water for all domestic purposes.

UNDERGROUND WATER CONDITIONS.

The geologic conditions bring out prominently marked differences in the underground water conditions of the different parts of the State. In south Georgia, or the Coastal Plain, the numerous beds of sand and porous limestones with their gradual dip southward present favorable conditions for deep wells. In the crystalline and Paleozoic areas, where the formations are much folded and faulted, underground water reaches the surface by numerous springs. In the one case the deep-seated underground waters reach the surface through artificial openings made by the drill, and in the other they come up through open fissures or along bedding planes of the rock. In the first case the underground waters are far more liable to become contaminated by surface impurities than in the other. This is due to the high or steep dip of the water-bearing strata. In south Georgia the underground waters in most cases probably flow through several miles of porous limestones or sands before reaching the deep wells, but in the northern part of the State wells equally as deep may be supplied with water falling as rain only a few hundred yards distant.

The conditions governing the water supply of shallow wells are practically the same in all parts of the State, especially where the wells obtain water from surficial deposits and residual clays.

The water from the shallow wells supplying small towns in north Georgia was usually found to be in fair sanitary condition, but in a

few instances analyses made in the laboratory of the State geological survey gave unmistakable evidence of sewage contamination. Certain local geologic conditions, which are peculiar to the northern portion of the State, seem to be the cause of this contamination. They will be described somewhat in detail.

All of the rivers and large streams throughout the crystalline and the Paleozoic areas traverse valleys of erosion which vary in width

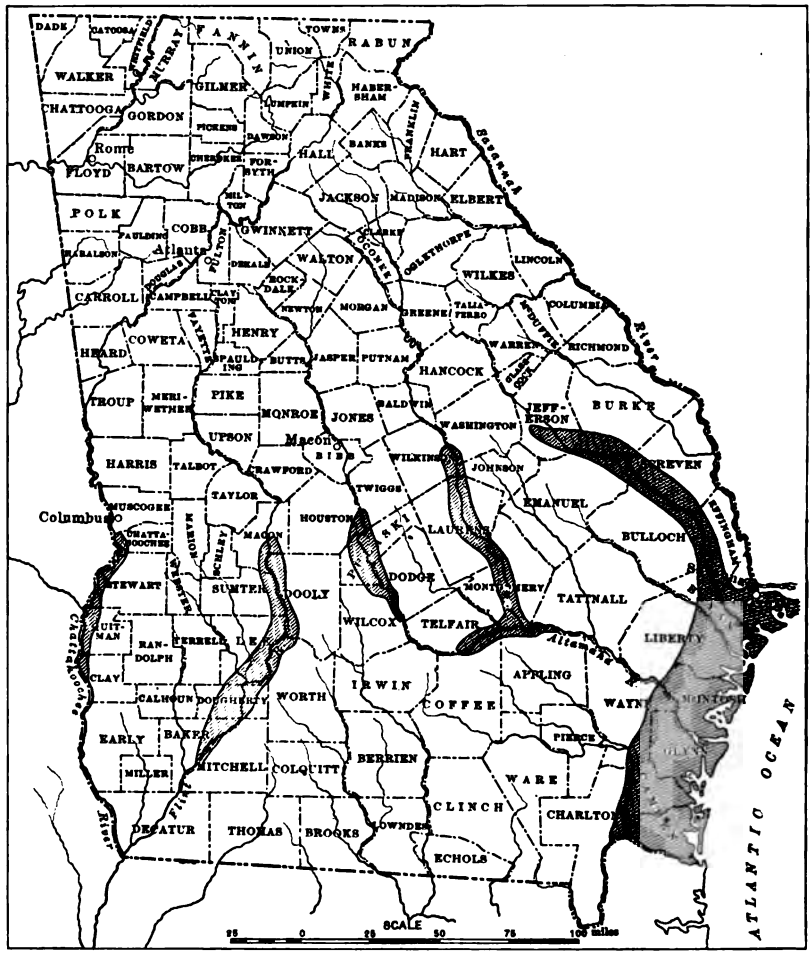

FIG 21.—Areas of flowing wells in Georgia. Flowing wells may be obtained in shaded areas.

from a few hundred yards or less to a mile or more. These valleys, parts of which now lie several feet above the present flood plain of the river, are often covered to the depth of many feet with alluvial deposits left by the stream when it flowed at a higher level. The deposits usually occur in two layers. The lower layer, which lies directly upon the eroded edges of the underlying rocks, consists

chiefly of coarse waterworn gravel and rounded stones, the latter often attaining a weight of many pounds. The thickness of this layer is variable and depends somewhat upon the irregular eroded surface of the underlying rock, but generally it is from 10 feet to a few inches. The upper layer, which is usually much thicker than the lower, is made up largely of silt or sandy clays. The two layers are conformable and have the same dip as the eroded surface of the underlying rock. This gives to the entire surficial deposit a gradual slope toward the center of the valley or the present channel of the stream. In many places the upper of the two surficial beds has been removed by erosion along the edges of the valley so that the underlying gravel is exposed. These exposed edges of the gravel beds present most favorable conditions for taking up the surface waters as they escape from the adjacent hillsides to the valley below after hard showers. These beds form a very imperfect filter and, as a consequence, the well water obtained from them is liable to become contaminated by surface impurities.

In north Georgia some of the towns along the rivers depend for water supply almost entirely upon surface wells penetrating these gravel beds. In laying out such towns it has been the custom to locate the business houses and the residences near the center of the valley, and the barns and stables along the margin near the outcrop of the gravel beds. In one town a row of factory houses was built along the outcrop of these gravel beds and there was an epidemic of typhoid fever throughout the town. Another town where the well waters were contaminated had suffered from a most violent epidemic of typhoid fever a few years previous. With a comparatively small outlay all of these towns can be supplied with excellent water from the mountain streams.

MINERAL SPRINGS.

Ten springs in Georgia reported sales of water in 1902. The total amount sold was 419,100 gallons, valued at $60,797. The springs are as follows:

Artesian Lithia Well, Austell, Cobb County.
Bowden Lithia Springs, Lithia Springs, Douglas County.
Catoosa Springs, Catoosa County.
Daniel Mineral Spring, near Union Point, Greene County.
Hughes Mineral Springs, near Rome, Floyd County.
Medlock Lithia Springs, Austell, Cobb County.
Ponce de Leon Spring, near Atlanta, Fulton County.
Salt Spring Lithia Well, Austell, Cobb County.
Siloam Healing Springs, near South Atlanta, Fulton County.
Sulpho-Magnesia Lithia Spring, near Austell, Cobb County.

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FLORIDA.

By M. L. Fuller.

Florida, unlike any other State except Louisiana, lies wholly within the Coastal Plain, although Delaware and Mississippi include only very small areas of older rocks. While in both geology and topography it resembles certain portions of the Coastal Plain region in other States, it is, as a whole, unique in its characteristics.

TOPOGRAPHY.

The relief of Florida is the lowest of any of the Eastern States, only about a quarter of its area standing above the 100-foot level, while only a few isolated points exceed 200 feet in height. Starting in the western portion of the State the highland belt skirts the northern boundary to Tallahassee, beyond which it extends southward along the center of the peninsula to a point east of Tampa. Its eastern border stretches northward a few miles west of St. Johns River to the northern boundary of the State northwest of Jacksonville. In this region soft limestones occur extensively, and there are, especially in the peninsula, many sinks and depressions, which are frequently occupied by ponds, lakes, or marshes. It is the gathering ground of the flowing waters encountered in the wells nearer the coast. On each side of the highlands the land slopes toward the coast, becoming at the same time freer from sinks and similar irregularities, but more or less cut by stream channels. Along the coasts on both sides of the southern portion of the peninsula are numerous low-lying islands or reefs of coral, shell fragments, or other material. The interior of the southern portion of the peninsula is occupied largely by vast swamps, of which the Everglades is the most extensive and best known.

The population is largely confined to the highlands. There are a few cities and villages near the Gulf coast west of the Tallahassee region and a considerable number about Tampa Bay. The Gulf coast is otherwise thinly inhabited. On the Atlantic side there is a line of villages and towns along the coast, but south of Titusville the interior is largely uninhabited. Key West and a few villages and towns are located on the keys and islands.

GEOLOGY.[a]

The axis of the peninsula of Florida consists largely of rotten cavernous limestone, white, gray, or yellow in color and of the Tertiary age. The main belt of these beds extends from the vicinity of Taylor, Madison, and Suwanee counties southeastward to Pasco County and vicinity. On the west the Lower Oligocene limestones are separated from the coast by a strip of Upper Oligocene beds, consisting of somewhat harder and more massive limestones with occasional beds of clay. The Upper Oligocene beds extend northwestward parallel with the Gulf shore to the western limits of the State. On the east the Lower Oligocene belt is limited by Octawaha River, beyond which are beds of Miocene age which extend nearly or quite to the coast. Toward the west a strip of Miocene parallels the coast, lying south of the Upper Oligocene, from at least Ochlockonee River on the east to Apalachicola River on the west. In the southern portion of the State the surficial rocks are of late Tertiary age, mainly Pliocene, and consist of marls, gray, green and blue clays, soft limestones, shale beds, etc. In the central part of the northern portion of the peninsula great thicknesses of sands, mainly of Quaternary age, cover the older rocks, while along the northern boundary in the western part of the State occurs the southern edge of the mantle of yellow sands, etc., generally known as the Lafayette formation. Local deposits of coquina and other late Pliocene and Quaternary materials occur at a number of points near the coast. The structure of the peninsula is supposed to be anticlinal, and the occurrence of artesian water would appear to bear out the assumption. Except along the belt of Lower Oligocene limestones, where the land rises to an elevation of about 250 feet, and in a few of the sand hills the region is very low.

UNDERGROUND WATERS.

Highland area.—Along the northern border of the State and in the highlands extending southward along the center of the peninsula the elevation of the surface generally precludes flowing wells, the region being one of catchment rather than of discharge. There is, nevertheless, frequently a range of 75 feet or more in the local elevation of the surface in this region, and flowing wells are not uncommon. They depend, however, mainly on local conditions, artesian areas of any extent being absent. The waters seldom rise more than 10 feet above the surface even when the wells are located in the lowest depressions. Fairly good water may be obtained in most instances from drilled wells of moderate depth, but generally pumping has to be resorted to.

[a] Compiled from data furnished by T. Wayland Vaughan.

Many of the depressions and channels of the highland area are marked by springs, some of which have been developed as resorts, while the waters of others are placed on the market for medicinal purposes. The springs are numerous and frequently of large size, giving rise, as in the case of Silver Springs, to streams navigable to their source. The waters, though hard, generally contain little sulphur and iron in solution.

West coast.—From the highland area the surface gradually slopes

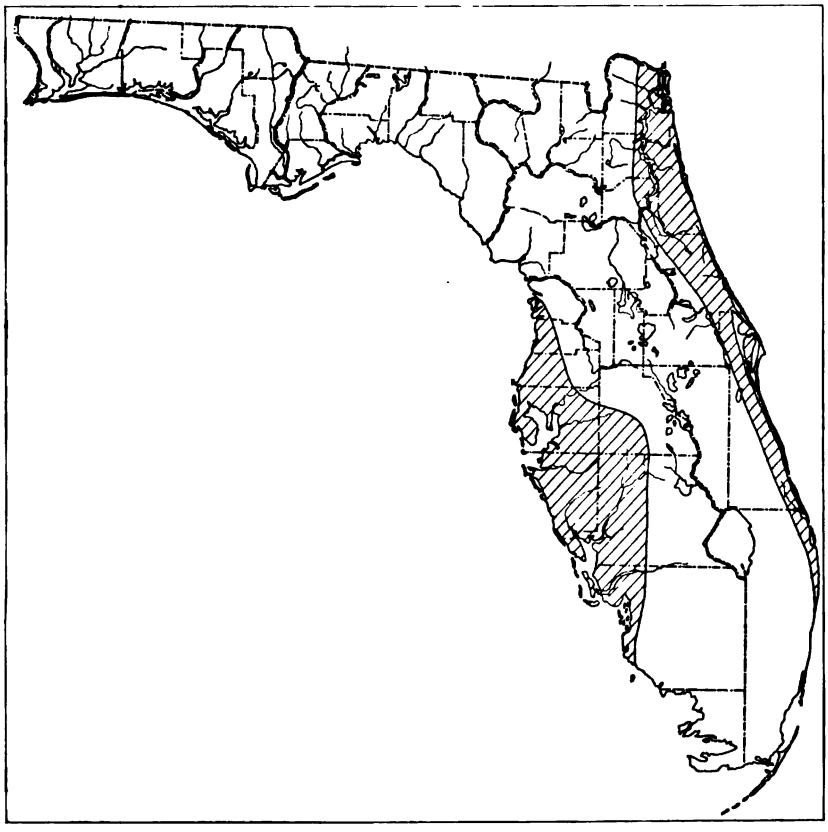

FIG. 22.—Principal artesian areas of Florida.

westward and southward to the coast. The area, as a whole, is very thinly settled, and relatively few wells have been drilled. In Hillsboro and Manatee counties, bordering upon Tampa Bay, and in the region extending into Polk County on the east, there is a considerable number of flowing wells. Flowing water is also found occasionally from Perry County westward to the western limits of the State, and it is probable that it could generally be obtained if the region was thoroughly tested. The land, however, is relatively low and ill adapted

to settlement, and, moreover, contains numerous streams and springs, some of the latter forming streams of considerable size. The waters are generally charged with sulphur and are undesirable for many purposes.

East coast.—Most of the flowing wells of Florida are located along a strip from 20 to 40 miles in width, following the east coast from the northern boundary of the State southward to beyond Jupiter Point. The wells are most numerous along St. Johns River, which lies but a few feet above sea level and along the so-called Indian River between the main coast and the outlying reefs. The waters frequently rise 10 feet or more above sea level, and in some cases are reported to rise as high as 50 feet, indicating that the waters are derived from the highlands of the interior. This tends to bear out the assumption which has been made as to the arched structure of the rocks of the peninsula. Artesian wells are also found along the reefs and islands, but the shallow wells in such locations are brackish.

The waters from the flowing wells of this belt are extensively utilized for irrigation throughout the entire strip, both on the mainland and on the islands or keys. They are usually obtained at depths of from 200 to 400 feet, but occasionally wells are drilled to great depths. A few very deep wells failed to secure satisfactory supplies.

Springs of considerable volume, generally of sulphur water, are found along St. Johns River and on the coast.

Sand area.—Overlying a considerable area in the north-central part of the peninsula and to a lesser extent elsewhere are extensive deposits of sands of Quaternary age. Throughout this region the ordinary wells are mainly of the driven type. The depth is commonly from 10 to 100 feet, depending largely upon the elevation at which the well is started. The water, though hard, is generally not otherwise mineralized. In most instances it is reported to be satisfactory as regards health, but in some regions is not considered desirable for drinking purposes.

MINERAL SPRINGS.

In 1902 sales of mineral water were reported by the following springs:[a]

Hampton Spring, Rocky Creek, Taylor County.
Magnolia Springs, Magnolia Springs, Clay County.
Orange City Mineral Spring, Orange City, Volusia County.
Panacea Mineral Springs, Wakulla County.
White Sulphur Springs, White Springs, Hamilton County.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

The aggregate output is reported as 21,900 gallons, with a value of $8,277.

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ALABAMA.

By Eugene Allen Smith.

CRYSTALLINE SCHISTS.

Under this head are included both the igneous and the metamorphic sedimentary rocks, which from their close texture are not very permeable, and hence are poorly adapted to absorbing and storing underground waters, but which are very generally covered with a mantle of sandy clays, the result of weathering, which yield an ample supply of water to springs and shallow wells. While the conditions are as a rule unfavorable for obtaining artesian waters, there are two wells at Alexander which yield abundant water but do not overflow.

NONCRYSTALLINE FORMATIONS.

The noncrystalline formations are found in northeastern Alabama, and together with the crystalline schists cover two-fifths of the State. The constituent strata are sandstones, shales, and limestones, in many alternations and of various degrees of purity. Owing to folding and other movements these strata, with the exception of the Coal Measures, have a very decided dip, generally toward the southeast. They are not very porous; but the sandstones and conglomerates, when their pores are not too much clogged with argillaceous and calcareous material, are the most permeable.

Springs and shallow wells.—In all the Paleozoic series, and especially in the Carboniferous, the siliceous rocks above mentioned are the sources of springs and shallow wells which yield pure freestone water, holding in solution 12 grains or less of mineral matters, mainly the carbonates of sodium and calcium.

The shales are practically impervious, and where they prevail, as in the flatwoods of the Cambrian in the Coosa Valley above Gadsden, in the central belts of the anticlinal valleys, and in some parts of the coal fields, most of the surface springs go dry in summer and fall months. In some parts of the flatwoods the waters from the shales are charged with mineral salts, especially the sulphates of calcium and magnesium—containing as high as 127 grains to the gallon. From certain

black bituminous shales of the Devonian containing disseminated pyrites are obtained strong sulphur waters that are known beyond the limits of the State. Such waters occur at Blount, Shelby, St. Clair, Talladega, and Alabama White Sulphur Springs.

The limestones are very generally fissured, channeled, and traversed by caves. Surface springs in limestone are therefore not important, except where they are formed by the emergence of underground streams. The "big springs," or limestone springs, thus originating characterize particularly the Knox dolomite of the Silurian and the lower Eocarboniferous formation. Some of the most noted of these big springs are at Tuscumbia, Huntsville, Montevallo, Talladega, and Jacksonville. The water is always charged with carbonate of lime.

Artesian systems.—The compactness and the steep dip of the rocks in the Paleozoic area do not offer favorable conditions for artesian wells, yet in a few cases deep borings have been successful. Thus at Anniston several wells in Cambrian strata have a depth of 250 to 500 feet, and the water rises nearly to the surface, but does not overflow. The supply is ample for the furnaces for which the wells were bored. On the southeastern slope of Red Mountain, near Gate City, there are four borings which reach depths of 25, 85, 103, and 344 feet. From two of these the water overflows; in the others, on slightly higher ground, it rises nearly to the surface.

In the Tennessee Valley, west of the meridian of Huntsville, the Eocarboniferous strata have a moderate southerly dip, and in most of the deep borings the water rises usually to within 30 feet of the surface, as near Sheffield and Russellville. A well near Decatur flows about 10 gallons per minute. This well was bored seventy-five years ago, and there has been no perceptible diminution during this time. In the Coal Measures of the Warrior basin the moderate and uniform dip of the strata is favorable to artesian wells, but the texture of the sandstones and other strata is not. Deep borings about Cullman and Tuscaloosa reach water which rises in the wells and can be pumped. At Jasper a deep well overflowed for some years after it was bored, but does not now.

Several borings in and near Tuscaloosa penetrate the Coal Measures and get a fairly good supply of water which rises in the wells but does not overflow. At the furnace of the Central Coal and Iron Company the well yields 500 gallons per minute. The water contains sodium chloride and the salts of magnesium and calcium.

COASTAL PLAIN.

In the Coastal Plain region, which includes about three-fifths of the State, the most important rocks are Cretaceous and Tertiary. The Cretaceous overlies the Paleozoic unconformably, and is in turn overlain by the Tertiary. The strata of both series are composed of alter-

nating beds of sands, clays, and limestones, and have a slight Gulfward dip, which averages 40 feet to the mile. The surface of the country slopes in the same direction, but at a much less rapid rate, the elevation being about 600 feet above tide on the landward margin, and 200 feet in the two coast counties. Thus the lithologic and physical characters, the arrangement, and the gentle uniform southward slope of the component beds provide requisite conditions for artesian systems.

The Cretaceous and Tertiary rocks are covered unconformably by one, and in some places by two, formations of much later date—the Lafayette of Quaternary age and the Grand Gulf of late Tertiary or possibly Quaternary. The Lafayette is far more extensive than the Grand Gulf group, as it covers or has covered the entire Coastal Plain, and sometimes for miles overlaps the Paleozoic area. It was once probably continuous over this region, but it is now much dissected, and has been almost entirely removed on some areas, especially the chalk of the Cretaceous and the post-oak flatwoods of the Tertiary. The Grand Gulf group, on the other hand, is confined to the lower counties. In the western half of this region it overlaps the Miocene and the uppermost (St. Stephens) formation of the Eocene. Toward the east it covers parts of the Claiborne and even of the "Lignitic," and extends to the border of the Cretaceous.

The underground waters in the Coastal Plain are hence obtained from two sources—the artesian water from older rocks (Cretaceous and Tertiary) and the surface waters from the two surface mantles.

SPRINGS AND SHALLOW WELLS.

The Lafayette formation, consisting of red sandy loam overlying irregular beds of pebbles and averaging 20 to 25 feet in thickness, is most admirably adapted for absorbing and storing the rainfall. At its contact with the underlying older formations, pure freestone water occurs in springs, and may be made available everywhere by means of shallow wells. As the water percolates through sands and pebbles, it takes in solution a very small amount of mineral matter, generally less than 3 grains to the gallon, of which carbonate of lime is the chief ingredient. Wherever this mantle is found in patches of considerable extent, a never failing supply of the purest water may be counted on, and the country is traversed by perennial streams. However, it does not afford the requisite conditions for artesian systems, (1) because of the great irregularity in the stratification due to erosion and (2) because being a mantle it has a southward dip not greater than the slope of surface.

The Grand Gulf group resembles the Lafayette and underlies it directly wherever the two occur together, but is much more lim-

ited in distribution and more uniform and regular in stratification. It is therefore well adapted to serve as a water reservoir. Its waters, like those of the Lafayette, are in general exceptionally pure, though sometimes highly charged with dissolved salts, mainly carbonate of lime. In the best of them there are not more than 5 grains of mineral matter to the gallon. Freely flowing springs and perennial streams are not, however, so characteristic of this as of the Lafayette. Shallow ponds and depressions, where the moisture-loving plants constituting the "pine-barren" flora find their most favorable conditions of existence, are typical features of the Grand Gulf territory.

This formation is an admirable cover for artesian waters, because of the thick stratified clays in its upper members. Over a large portion of this region, notably about Brewton and Pollard and other localities in Escambia County, water of good quality flows from borings 100 to 400 feet deep. The water is obtained in part from the Grand Gulf group and in part from the underlying Tertiary beds.

Springs and shallow wells which obtain water from the older formations vary in character. If they have their origin in the great sand formations of the lowermost Cretaceous and of the Tertiary, they are numerous and reliable, though the water is sometimes unpalatable because of much dissolved mineral matter. In the limestone formations of the middle Cretaceous and upper Tertiary, surface waters are small in amount and unreliable, compelling recourse to artesian wells.

ARTESIAN WATER SYSTEMS.

The materials and the structure of the Coastal Plain formations are favorable to artesian wells, as the strata are composed of sands and clays in many alternations, and have a moderate and uniform dip southward.

The two lowermost divisions of the Cretaceous—the Tuscaloosa and the Eutaw—are prevailingly sands, alternating with sheets of clay. The Tuscaloosa is of fresh-water origin, while the Eutaw is a marine deposit. The water obtained from the Tuscaloosa beds holds usually less than 15 grains of dissolved solids to the gallon, mainly the carbonates of lime and sodium, with smaller proportions of sodium chloride and magnesium carbonate. The potable waters of the Eutaw sands, on the other hand, contain from 15 to 30 grains of solid matters per gallon, and the chloride and carbonate of sodium predominate, though occasionally the carbonate of lime is more abundant. Some of these waters are brines, holding as much as 260 grains of sodium chloride to the gallon.

In the area of the Selma chalk which immediately overlies the Eutaw surface waters are practically nonexistant except in wet weather, and recourse must be had to artesian wells or to cisterns sunk in the solid chalk rock. In this section most of the artesian wells obtain water from the Eutaw sands, which are 300 feet thick and in

which four water horizons are recognized by well borers. The fourth or lowermost is generally the strongest and most reliable, yielding generally flowing water where the altitude is not over 215 feet above tide. In the eastern part of this area, in Russell County particularly, the water sometimes rises to altitudes of 300 feet.

Along the southern border of the chalk, as at Livingston and Linden, artesian borings must traverse the entire thickness of the limestone—1,000 feet—before reaching the water-bearing sands. Near the northern border, of course, the borings are much shallower, but here, in order to get a copious and reliable water supply, the borings must frequently go deep into the Tuscaloosa strata underlying the Eutaw. The upper members of the Tuscaloosa contain much purplish or reddish clay, generally referred to by the well borers as the "pink kaolin."

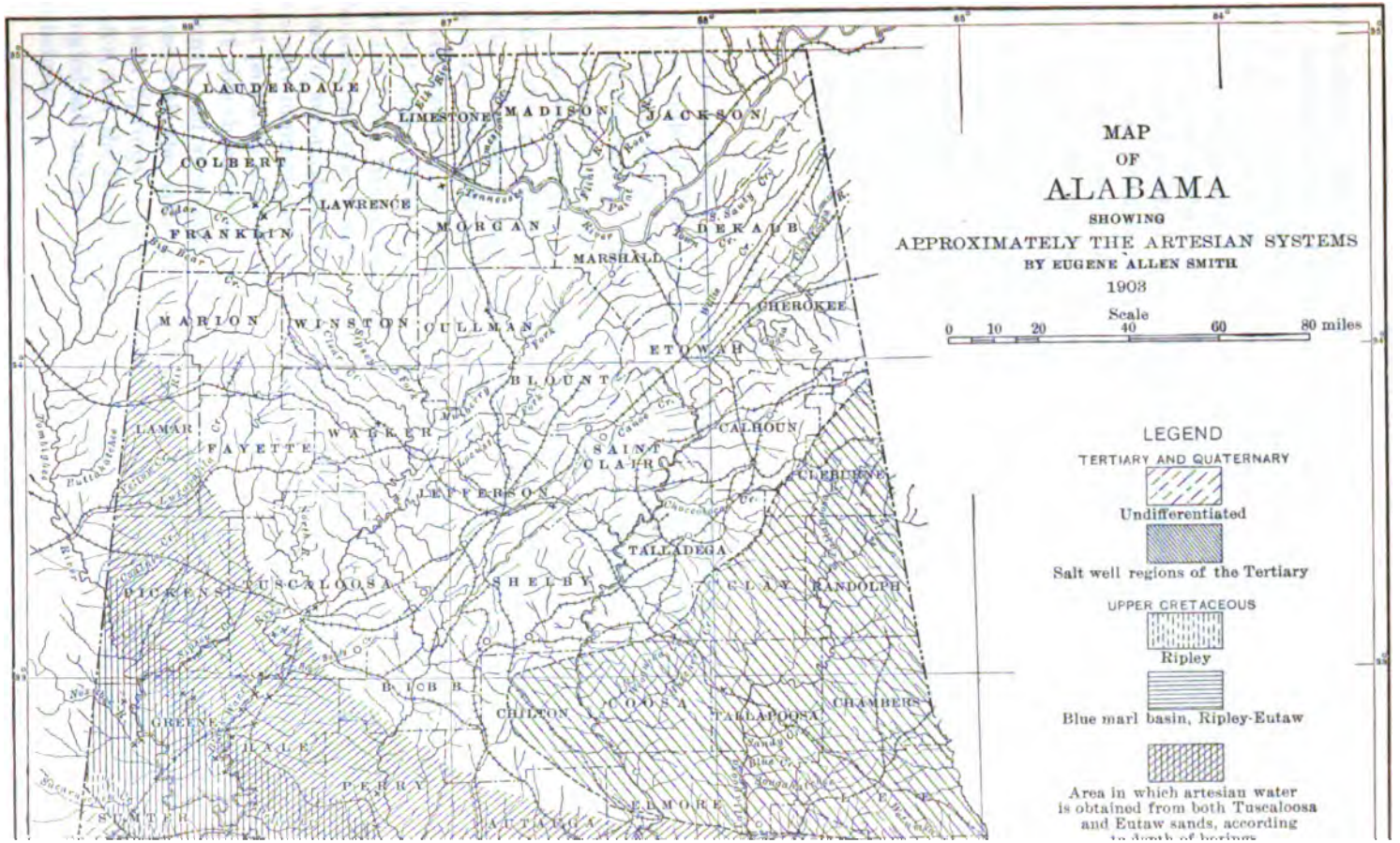
Hundreds of artesian wells supply the plantations of the prairie belt across the State and many cities, among which are Eutaw, Greensboro, Marion, Selma, Demopolis, Uniontown, Montgomery, and Union Springs.

The uppermost of the Cretaceous formations, the Ripley, is formed of calcareous sands which weather at surface into loose sands and are well adapted to collecting and storing surface waters. Springs and shallow wells in consequence generally afford an ample supply of water, which is usually limy. Below the belt of weathering, however, these beds do not appear to be very permeable, as is shown by the failure of most of the deep borings into them.

Near the base of the Tertiary, west of Alabama River, 200 feet of massive clays give rise to the post-oak flatwoods which are characterized by heavy cold soils, defective drainage, and deficiency of springs and surface waters generally during the dry seasons. The shallow wells sunk into these clays give a scanty and unreliable supply of water which is often unfit to drink because of excess of dissolved salts, especially magnesium sulphate, which is sometimes present to the amount of 100 to 210 grains per gallon. Waters of this character from wells near York and Curls, in Sumter County, are extensively used for medicinal purposes. The failure of the underlying Ripley sands to supply good artesian water is a great drawback to the flatwoods territory.

East of Alabama River the prevailing beds near the base of the Tertiary are limestones, which in Barbour County are of sufficient thickness to give rise to caverns, "Big Springs," and water conditions similar to those of other limestone areas.

In the "Lignitic" group of the Tertiary the alternations of sands and clays and their uniform moderate dip are favorable to artesian systems, and two artesian-water horizons are well known, the Nanafalia and the


MAP
OF
ALABAMA
SHOWING
APPROXIMATELY THE ARTESIAN SYSTEMS
BY EUGENE ALLEN SMITH
1903
Scale
0 10 20 40 60 80 miles
LEGEND
TERTIARY AND QUATERNARY
Undifferentiated
Salt well regions of the Tertiary
UPPER CRETACEOUS
Ripley
Blue marl basin, Ripley-Eutaw
Area in which artesian water is obtained from both Tuscaloosa and Eutaw sands, according
LAUDERDALE
LIMESTONE
MADISON
JACKSON
COLBERT
LAWRENCE
FRANKLIN
MORGAN
DE KALB
MARSHALL
CHEROKEE
MARION
WINSTON
CULLMAN
ETOWAH
BLOUNT
LAMAR
FAYETTE
WALKER
SAINT CLAIR
CALHOUN
CLEBURNE
JEFFERSON
TALLADEGA
PICKENS
TUSCALOOSA
SHELBY
CLAY
RANDOLPH
BIBB
CHILTON
COOSA
TALLAPOOSA
CHAMBERS
GREENE
HALE
PERRY
ELMORE
SUMTER
MACON

Hatchetigbee. The same conditions prevail, also, in the lower part of the Claiborne division, but the St. Stephens limestone at the top of the Eocene is, of course, not to be counted among the good water bearers. In the Tertiary area of Alabama the artesian wells are not so common as in Mississippi, but there are enough of them to prove that artesian water of good quality may be had in abundance. The abundance of good water furnished by the Lafayette formation has rendered the sinking of artesian wells for individual use unnecessary, but many towns in the lower counties have recourse to deep borings for their supplies, and the number of artesian wells increases yearly.

The late Tertiary (Miocene) formations underlying Mobile and Baldwin counties, have likewise all the requisites of artesian systems. In and near the city of Mobile several wells, 700 to 1,550 feet deep, obtain abundant water, which is sometimes potable and sometimes excessively salty. On the coast at Bayou La Batre an artesian well supplies the canning factory. It is 580 feet deep, and the water rises 15 feet above the surface. The water holds only 14.4 grains of dissolved mineral salts per gallon, chiefly the chloride and carbonate of sodium.

BRINE AND GAS WELLS.

This record would be incomplete without some reference to the brine and gas wells of Washington and Clarke counties, which occur along the southern border of the Hatchetigbee anticline and its southeastward prolongation. Most of these borings are located in the palmetto flats of small creeks, near their mouths, and at the base of hills capped with the St. Stephens limestone. Beginning in Claiborne strata at the surface they penetrate 100 to 400 feet into the underlying Hatchetigbee sands. The water rises to the surface in all cases, and at many points there are natural brine oozes, which may be converted into reservoirs of salt water by inclosing an area of 15 or 20 feet diameter by a palisade of heavy timbers and digging out the interior. During the civil war the brine from these wells and reservoirs was extensively used in the manufacture of salt. In most cases natural gas in considerable quantity accompanies the salt water, and frequently the weak brines are strongly impregnated with sulphuretted hydrogen gas, producing the most palatable sulphur waters in the State.

Of this character are the waters of the well at Jackson, in Clarke County, and at several of the salt works. Natural gas is also associated with the salt waters from other horizons. The deep well at Cullom Springs, Choctaw County, yields much gas along with salt water, and the Bascomb well near Mobile throws up a foaming jet of mingled salt and gas, which on ignition burns with a flame several feet in height.

MINERAL SPRINGS.

Of the many large springs only eight were reported in 1902 as utilizing their water for shipment. These springs are as follows:

Bailey Springs, Bailey Springs, Lauderdale County.
Cherokee Spring, Citronelle, Mobile County.
Healing Springs, Healing Springs, Washington County.
Ingram Lithia Springs, Calhoun County.
MacGregor Spring, Spring Hill, Mobile County.
Talladega Springs, Talladega County.
Wilkinson's Matchless Mineral Wells, Greenville, Butler County.
York Aperient Well, York, Sumter County.

The total output is placed at 68,050 gallons, with a value of $28,109.

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MISSISSIPPI.

By L. C. Johnson.

GEOLOGY.

The geologic structure of Mississippi is very simple, but the details of the distribution of various formations are hard to make out owing to the extent to which the underlying rocks are concealed by more recent deposits, such as the river alluvium, loess, and Orange sand or Lafayette formation.

The oldest rocks in the State are comprised in a series of limestones of Mississippian ("Lower Carboniferous") age, which outcrop in northeastern Mississippi and cover much of Tishomingo County, and a small portion of Itawamba County. South, southwest, and west of this older rock mass outcrop successive parallel bands of later rocks, which dip away from the Carboniferous mass in a direction which varies from south to west. Along the Alabama State line, for example, the dip is practically due south; along the Tennessee line it is almost due west, while in intervening sections it is southwest. The amount is slight, averaging probably about 25 to 35 feet to the mile. Southward or westward from Tishomingo County newer and newer series of rocks outcrop until recent alluvial deposits are found along the Gulf and Mississippi River.

The distribution of the more important of the geologic formations are shown in the accompanying sketch map (fig. 23).

MISSISSIPPIAN ("LOWER CARBONIFEROUS") ROCKS.

The Mississippian rocks occupy an area covering portions of Tishomingo and Itawamba counties. They consist largely of limestones. They abound in springs, which are so numerous and accessible that there has been little demand for deep borings, though open wells with a depth of 100 feet and yielding good water are not uncommon. A few of the well waters are mineralized. Some of the springs issue from the Mississippian rocks and some from the Cretaceous sands which thinly cover the harder rocks along the borders of the area.

Two important springs occur in the area. The first, known as Bay Spring, is located near the falls of Mackay Creek, and may have its source within fissures of the limestone. The waters are of normal purity. The second spring, the Iuka, is a medicinal spring containing

considerable amounts of sulphur, iron, sodium, and calcium. It is located in the city of the same name and has been developed as a health and pleasure resort.

CRETACEOUS DEPOSITS.

Southwest of the Mississippian area are the Cretaceous formations. These occupy a belt outcropping around the area of Mississippian rocks. In general, water may be obtained in this section by wells at

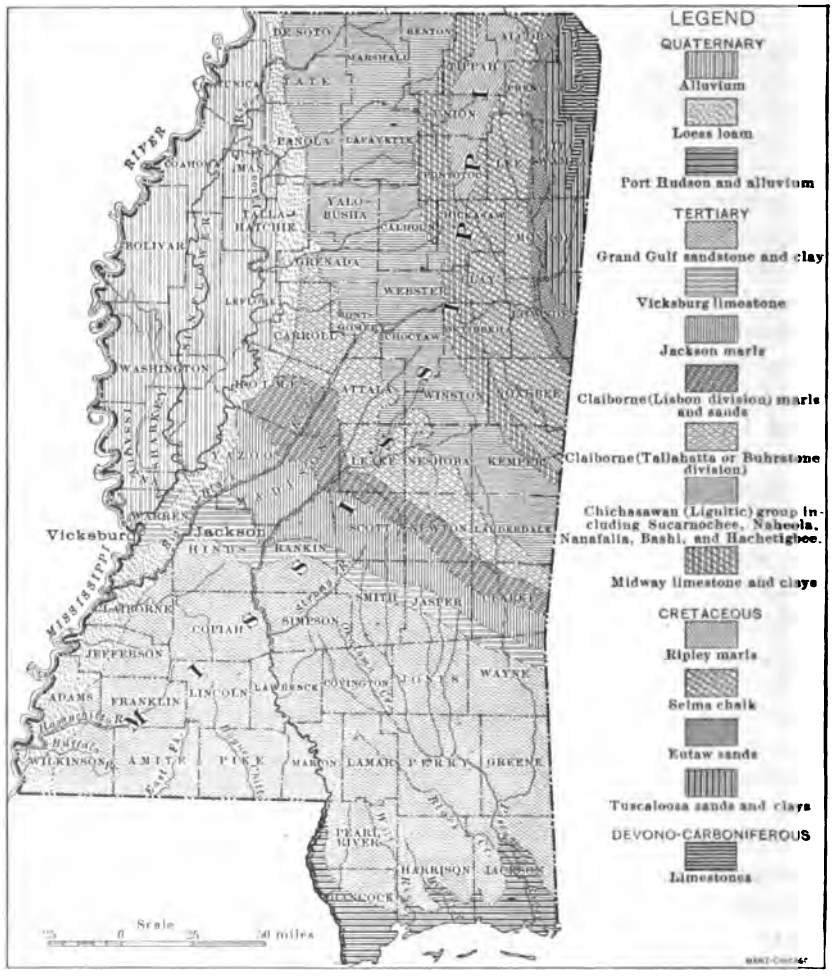

FIG. 23.—Geologic sketch map of Mississippi.

a depth of from 200 to 1,500 feet, the depth increasing with the distance from the contact with the Mississippian. Few of the wells flow, but the water generally rises to within easy pumping distance of the surface. In quality, the water is usually more or less alkaline, but in a few wells it is pure and soft.

Tuscaloosa formation.—This oldest Cretaceous formation, which consists largely of variable beds of sands and clays, is separated into two parts by a persistent bed of purplish clay. The upper portion generally yields only small amounts of unsatisfactory water, but the lower half and the sandy bed at the top of the upper half yield copious supplies of good water. Wells drawing their supplies from this formation are located at Columbus, Lowndes County, at Gattman, Aberdeen, and Amory, Monroe County, and elsewhere. Springs are not uncommon where streams have cut into the deposits. Kolola Spring on Buttahatchee River, in Lowndes County, has considerable reputation because of the medicinal properties of its water, which carries sodium, potassium, magnesium, calcium, and iron, especially the latter.

Eutaw beds.—The name Eutaw has been applied to the sandy beds between the Tuscaloosa formation and the overlying Selma chalk. In Alabama the Eutaw beds usually yield saline waters, but in Mississippi they are not water bearing, the wells generally passing through them into the underlying Tuscaloosa formation.

Selma chalk or Rotten limestone.—In Mississippi this formation is not a water-bearer, but throughout the prairie regions of the northeastern part of the State it serves as a cap rock to the water-bearing bed at the top of the Tuscaloosa formation. There are more than a hundred deep wells each in Noxubee, Lowndes, Clay, Monroe, and Lee counties, and there is a large number of wells in Oktibbeha, Chickasaw, Prentiss, and Union counties. In the western parts of these counties there are fewer wells than in the eastern, not because of the impossibility of obtaining water, but because the wells must be deeper and are therefore more costly.

The regularity of the water-bearing beds as shown by the wells indicates there has been no material disturbance or dislocation of the deposits beyond a simple tilting westward from the contact of the Rotten limestone and Tuscaloosa beds at the rate of 25 feet to the mile.

Ripley beds.—The Ripley beds in Mississippi consist of a series of sands, marls, and limestones outcropping west and southwest of the Selma chalk or Rotten limestone. Until recently no water supplies of importance had been obtained from these beds, but abundant water has lately been found in a number of wells at Ecru, in Pontotoc County. The wells appear to be located in a local syncline or trough and have an average depth of about 200 feet. Most of them flow at the surface.

Springs are not abundant in the Ripley beds, but they frequently occur along its contact with the overlying Lafayette sands and gravel. The large Blue Mountain Spring is an example of this type. It carries a small amount of calcium and magnesium carbonates, derived, it is supposed, from the underlying marls of the Ripley beds.

TERTIARY DEPOSITS.

Westward from the limits of the Selma chalk or Rotten limestone to the delta district, and southward to the southern portion of the State, lies the broad belt of Tertiary deposits, which have been divided into a considerable number of formations, each of which is considered below.

Midway.—The Midway beds consist of limestones overlying the Ripley sands, marls, etc. The thickness is slight and they do not carry any considerable amount of water.

"*Lignitic*" *group.*—One of the most important divisions of the Tertiary is the "Lignitic" group, which is further subdivided in Alabama into (1) the Sucarnochee, consisting of black clays, (2) the Naheola, (3) the Nanafalia, (4) the Bashi, and (5) the Hatchetigbee formations. The last four consist largely of gray lignitic clays, with occasional marl beds and some water-bearing sand.

The general structure of the region underlain by the Lignitic group is favorable to obtaining water, both by wells and springs. The surface elevation, however, is so nearly uniform that even deep borings seldom produce flowing wells. Where the streams have cut into the deposits numerous springs issue from the banks, except in the case of the Sucarnochee formation.

The Sucarnochee formation is a deep black clay, very impervious to water. Springs frequently issue from the more porous beds overlying it, but it is itself practically destitute of water.

The Naheola formation contains a few sandy beds yielding small flows of water. Wells at Lauderdale penetrate these beds at depths of from 100 to 200 feet, and obtain weak flows rising 2 or 3 feet above the surface. Similar wells have been obtained in this formation at scattering points elsewhere. Some of the largest springs of Mississippi appear at the contact of the Naheola with the underlying clays of the Sucarnochee formation. Like the Naheola these formations consist of grayish lignitic clays with occasional marl and sand beds. They are not important water horizons. At Meridian borings penetrated the "Lignitic" strata from the Hatchetigbee down to the Sucarnochee, but the water only rose to within 20 feet of the surface.

There are a number of springs from the Nanafalia formation, one of which, the Lauderdale, is of considerable importance. The waters, which carry considerable sulphur, issue from lignitic beds on a branch of the Sucarnochee River, near Lauderdale. A health resort has been developed at the spring.

The Hatchetigbee formation is similar to the preceding Lignitic formations, but carries thicker beds of sand, and is therefore a more important water-bearing formation. It underlies a considerable portion of the delta deposits, and is thought to be the source of water of

the wells drilled through the deposits of the delta at Memphis, Tenn., Tunica, Coahoma, Quitman, Tallahatchie, Leflore, Sunflower, Bolivar, and other places. The depth constantly increases toward the south and west from 850 to 1,300 feet.

The most important spring in the Hatchetigbee deposits is the Arundel Lithia Spring. The water issues from the Hatchetigbee sands, where Oktibbee River and Sowoshee Creek have removed the Buhrstone and cut away the sands down to the stiff clay beneath. Considerable amounts of the water are sold. The whole of the adjoining region is marked by numerous springs, but in general none of them have been improved nor the water marketed.

Tallahatta formation (*buhrstone*).—The Tallahatta formation consists essentially of a series of hard sandy beds, more or less porous in places, comprising the lower portion of the Claiborne group. It contains little water in itself, but forms an impervious cap rock to the water-bearing sands of the underlying Hatchetigbee. By its resistance to erosion the Tallahatta has given rise to an elevated ridge which is of much assistance in the location of water-bearing beds. Water which rises to a greater or less distance is almost always found beneath it, the local topography determining whether the well will flow or not. This horizon supplies the wells at Stonewall (300 feet), Quitman (500 feet), Enterprise (200 feet), all in Clarke County; at Grahams Switch (90 feet), and Meehan Junction, in Lauderdale County, and at Chunky and Hickory (500 feet), in Newton County. It is also probable that the artesian flows at West, Pickens, Durant, Tchula, and Lexington, in Holmes County, are from the same source. To the above list may possibly be added the deep wells at Jackson, Hinds County (964 feet), and at Canton, Madison County (1,020 feet), both of which, however, were bored through the Jackson and Claiborne marls before penetrating the Hatchetigbee beneath the buhrstone.

Lisbon formation (*calcareous Claiborne*).—This formation consists of marls and green sand, and has a total thickness of about 300 feet. It contains several minor beds of ferruginous water-bearing sands, but none of them are as persistent as the Hatchetigbee. One of these beds is encountered at 300 feet at Shubuta, and at 500 feet at Waynesboro. The water from these wells is colored by the iron, and is also highly alkaline.

A local sand bed of the Lisbon formation yields colorless, but chalybeate water in the double wells at Shubuta, and in the wells at De Soto and Pachuta. The water in the last well only comes within 20 feet of the surface.

Springs are by no means rare in the Lisbon area, but they are generally supposed to come from the overlying Lafayette sand. A few, however, are probably of deeper-seated origin. The Archusa Spring, near Quitman, Clarke County, is derived from these beds.

The water is sulphurous and alkaline. The Pierce Spring, near the banks of Bucatanna Creek, in eastern Clarke County, is also strongly mineralized. The Robinson Spring, in Madison County, which has been developed as a health resort, yields water similar to that of the springs in Clarke County.

Jackson and Vicksburg formations.—These two formations, which may be grouped together, consist of marls, clays, and limestone, the latter predominating in the upper or Vicksburg division. There are few sandy beds and artesian waters are generally lacking. The flowing wells located in the area of outcrop obtain water from the ferruginous sands of the Lisbon formation at Shubuta and Waynesboro, and from the Hatchetigbee sands at Jackson (964 feet) and Canton (1,020 feet). An important mineral well, known as the Cooper well, is located 3 miles east of Raymond. It is 90 feet deep, and at this point has been developed the most important health resort in the State. The water contains iron, magnesia, soda, and sulphur. Another well-known mineral well, near Hazlehurst, Copiah County, obtains water from this formation. The water is impregnated with sodium and magnesium chlorides and calcium sulphates. It occurs at a depth of 63 feet, probably in a lignite bed. A third mineral well of importance is the Godbold, 1¼ miles from Summit, Pike County.

Springs in the area of outcrop of this formation are really from the sands and gravels of the overlying Lafayette. The best known of these break out along Paulding Ridge, in Jasper County. Those issuing on the north side generally yield pure, soft water; those on the south are usually mineralized. The Phalti Spring (sec. 8, 2 N., R. 13 E.); Bay Spring, at Bayspring post-office; Donald's mineral spring, near Weems; and Vosburg and Stafford springs, in the same vicinity, are among the most important.

Grand Gulf group.—The Grand Gulf is by far the most extensive formation in the State, and consists of a variable series of sandstones, sands, and lignitic clays. Practically every sand bed, of which there are a great number, is water bearing, and supplies are obtained by dug, bored, and drilled wells. Where stream erosion has cut into the beds to any considerable distance springs occur. At Hattiesburg, Laurel, Brookhaven, and Natchez water is obtained at depths of from 200 to 400 feet, but only at Hattiesburg does it rise above the surface. There are considerable evidences of undulations of the beds in the Grand Gulf area, the flowing water at Hattiesburg being referred to a shallow synclinal trough at that point.

Among the springs and mineral wells may be mentioned the Mississippi Springs in Hinds County (sec. 2, T. 5 N., R. 4 E.); the Mammoth Mineral Springs, Perry County (secs. 24 and 25, T. 5 N., R. 14 W.); and Rawls Spring, 2 miles farther west. The Mammoth Spring, 6 miles northwest of Hattiesburg, is a large spring issuing from lig-

nitic clays. Both the Mammoth and Rawls springs are noted for the medicinal value of their waters.

QUATERNARY.

Lafayette sands and gravels.—The Lafayette formation is poorly defined, but may be considered as made up of a series of yellowish or orange sands and gravels occurring as a mantle over the outcropping edges of the Grand Gulf and other formations. Because of its sandy and gravelly character it contains, especially at the base, a large amount of water, which is usually pure and soft, and which is obtained by shallow wells.

Loess and loam.—The loess consists of fine fossiliferous yellowish silts, while the loam consists of browner silts, possibly produced by the weathering of the loess. The deposits occur over the Yazoo delta region in the northwestern part of the State. Only very small amounts of water can be obtained in the loess or loam, practically all of the wells passing through it into the underlying Lafayette or still older formations.

Pontchartrain clay and Biloxi sand.—The Pontchartrain clay is a greenish clay occurring in a narrow belt in the extreme southern part of the State, and separated from the coast by a very narrow strip of sandy beds, known as Biloxi sands. Shallow wells in these two formations everywhere obtain abundant water at shallow depths, although the quality is not always satisfactory. To obtain flowing water the wells must extend to the Grand Gulf formation. Water is found at depths of approximately 400, 600, 700, 850, and 900 feet.

The buckshot lands of the delta have sometimes been referred to the Port Hudson group, which includes the two formations under discussion. The water is generally fairly abundant and soft, but has not been found to be wholesome for drinking. In the northern part of the delta area water can be obtained from deep wells reaching to the Tertiary beds.

Alluvium.—Under alluvium are included the surface materials of the Mississippi delta region and the deposits in the lower portions of the courses of other large streams. The waters, though soft, are not regarded as wholesome.

MINERAL WATERS.

In 1902 shipments of mineral water were reported from the following seven springs:

Arundel Lithia Springs, near Meridian, Lauderdale County.
Browns Wells, Browns Wells, Copiah County.
Castalian Springs, near Durant, Holmes County.
Godbold Mineral Well, near Summit, Pike County.
Lowes Wells, Hazlehurst, Copiah County.
Robinson Mineral Springs, Robinson Springs, Madison County.
Stafford Mineral Springs, near Vosburg, Jasper County.

The aggregate amount sold is reported as 459,485 gallons, valued at $77,868.

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LOUISIANA AND SOUTHERN ARKANSAS.[a]

By A. C. Veatch.

GENERAL GEOLOGY.

Louisiana and Arkansas, south of Arkansas River and the mountains, have the same general structure as the great American Coastal Plain, of which they form a part. The land is highest toward the old plateau and mountain region to the northwest. The beds are for the most part unconsolidated, succeed one another in more or less regular succession, range in age from Cretaceous to Recent, and in general have a dip coastward that is greater than the slope of the surface. This relation of dip to surface slope supplies conditions which are favorable for artesian water, therefore flowing wells should be expected in many parts of the Coastal Plain. In some cases the leakage and resistance of the sands so reduces the pressure that the water will not flow, although the altitude of the well mouth is less than that of the point where the sands come to the surface and where the water enters; in others, erosion has so changed the surface of the plain that the well mouth, though south of the outcrop of the water-bearing bed, is higher, and the water, therefore, will not flow. In Louisiana and southern Arkansas the older beds slope toward the Mississippi Valley as well as toward the coast. Some of these older beds are very much disturbed and form peculiar, sharp domes, and as they often contain salt water, and are frequently broken by the folding, the salt water is free to pass into the sands of the surrounding younger formations. While these domes disturb the conditions in certain tracts, there are still larger areas in which wells have found good water. A study of these well records and of the general structure of the country shows that the following principal water horizons are present: Bingen sand, Nacatoch sand, Sabine sands, Catahoula sandstone, Pliocene and Quaternary sands and gravels.

The relation of these beds to one another is shown in figs. 24 and 25, and their geologic age and relation to adjacent beds are shown in the table following.

[a] A preliminary statement. A detailed report on this area, embodying records of all important wells and well prospects for each county is now in preparation and will be ready for distribution late in 1905.

Water-bearing value of geologic formations of Louisiana and southern Arkansas.

Period or formation.	Maximum thickness.	Water-bearing value.
Quaternary	[a] 2,000	Contains gravel and sand beds, which furnish the main supply of water in southern Louisiana.
Pliocene		As surficial deposits on the uplands and in the valleys, supply much of the shallow well water of this region.
Miocene	(?)	No surface outcrop, and hence probably of no importance as a water horizon.
Oligocene:		
Fleming	± 200	Clays and marly clays; no water-bearing value.
Catahoula	[b] 1,000	The coarser sandstone layers of this formation furnish excellent water. Three or four horizons have been developed.
Vicksburg	50–100	Exposed in only one part of the area and of no importance from a water standpoint.
Eocene:		
Jackson	500	Clays and clay marls with occasional sand beds; water generally hard and seldom developed.
Cockfield	500	The sandy beds occurring near the base of the formation are second in importance only to the Sabine.
Claiborne	500	Clays and clay marls containing sand beds of little importance as water horizons.
Sabine [c]	1,000	The sands of this formation are the important water horizons of the greater part of northern Louisiana and adjacent parts of Arkansas.
Midway	(?)	Exposed only to a limited extent in one part of the area, and unimportant as a water-bearer.
Upper Cretaceous:		
Arkadelphia	[d] 600	Clay beds, which serve to retain water in Washington sands.
Nacatoch	150–200	One of the most extensively developed water sands of this region. Very good water near the outcrop, but brackish in the embed.
Marlbrook	400	Clays, clay marls, and chalk; serve to retain water in the Bingen sands.
Annona	+100	
Brownstown	300	
Bingen	+500	Persistent sandy bed, furnishing water over a wide area.
Lower Cretaceous	[e] 550	Not known to contain any important water-bearing layers in this region, though the great development in eastern Texas would lead us to expect some development here.
Paleozoic	(?)	Hard rock layer very much disturbed. Contains water, but its occurrence can not be predicted until the geology of the region is minutely understood. In general, not very good field for water wells.

[a] Harris, G. D., Organic remains from the deep well at Galveston: Fourth Ann. Rept. Geol. Survey Texas, 1893, p. 118. Harris, G. D., Report of Louisiana Geol. Survey for 1902, p. 32.

[b] Based on dip calculations on the Sabine River, and on the thickness of these beds in the Alexandria, La., wells, 800+ feet.

[c] Name adopted to supplant Lignitic, taken from typical fossiliferous development of the formation on the Sabine River, in Sabine County, Tex., and Sabine Parish, La.

[d] Based on wells south of Hope, at Arkadelphia and Shreveport; may be in part Midway.

[e] Hill, R. T., The Mesozoic geology of southern Arkansas: Ann. Rept. Arkansas Geol. Survey for 1888, p. 188.

WATER HORIZONS.

Lower Cretaceous.—The lower Cretaceous occupies the wedge-shaped territory between the Paleozoic rocks and the Bingen sands (fig. 24). All deep wells in this region have thus far failed to yield water, though the extensive development of water sands in this group in Texas leads

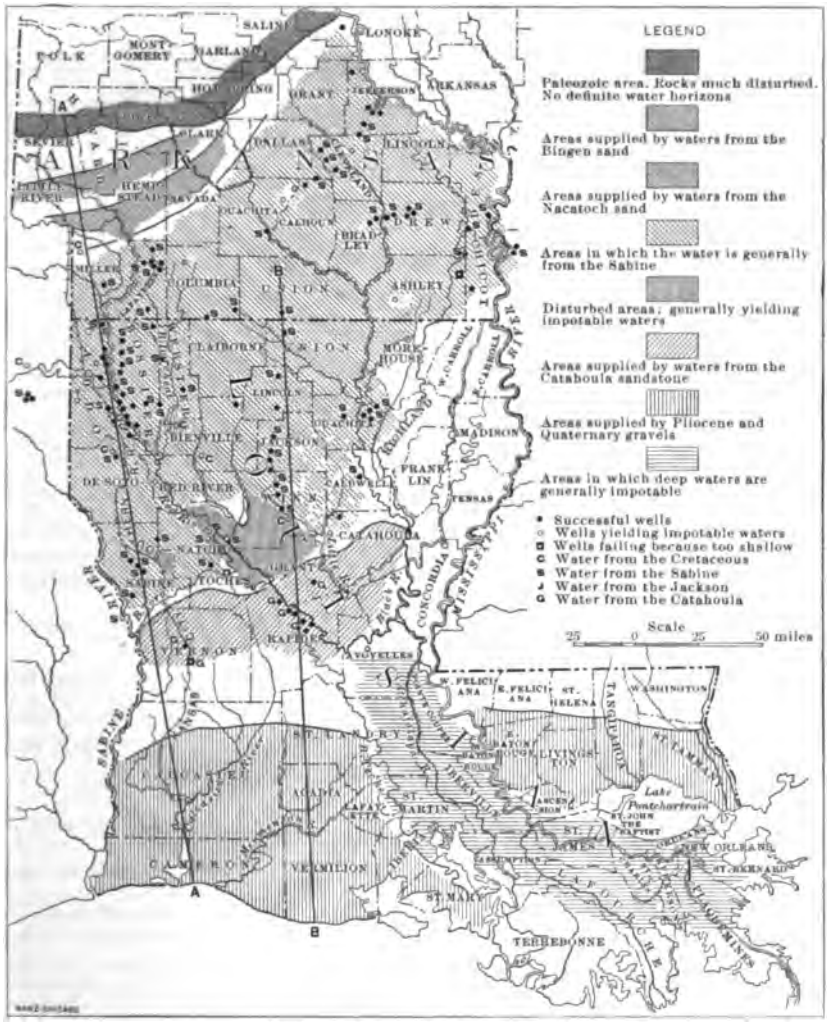


FIG. 24.—Deep-water prospects in Louisiana and southern Arkansas. A-A, line of section shown in fig. 26; B-B, line of section shown in fig. 27.

to the belief that further attempts, especially in the western part of the State, will not be fruitless. The best water-bearing sands are to be expected near the base of the Cretaceous or just above bed rock. The depths at which bed rock will be encountered may be roughly found by multiplying the distance in miles between the Paleozoic out-

crop and the point where the well is to be sunk by the average rate of slope of the bed-rock surface, 100 to 125 feet per mile.

Bingen sand.[a]—The Bingen sand comes to the surface along and south of the line shown in figs. 24 and 25. Along this line shallow wells are, therefore, the rule, but as the sand dips at a rate of 50 to 75 feet per

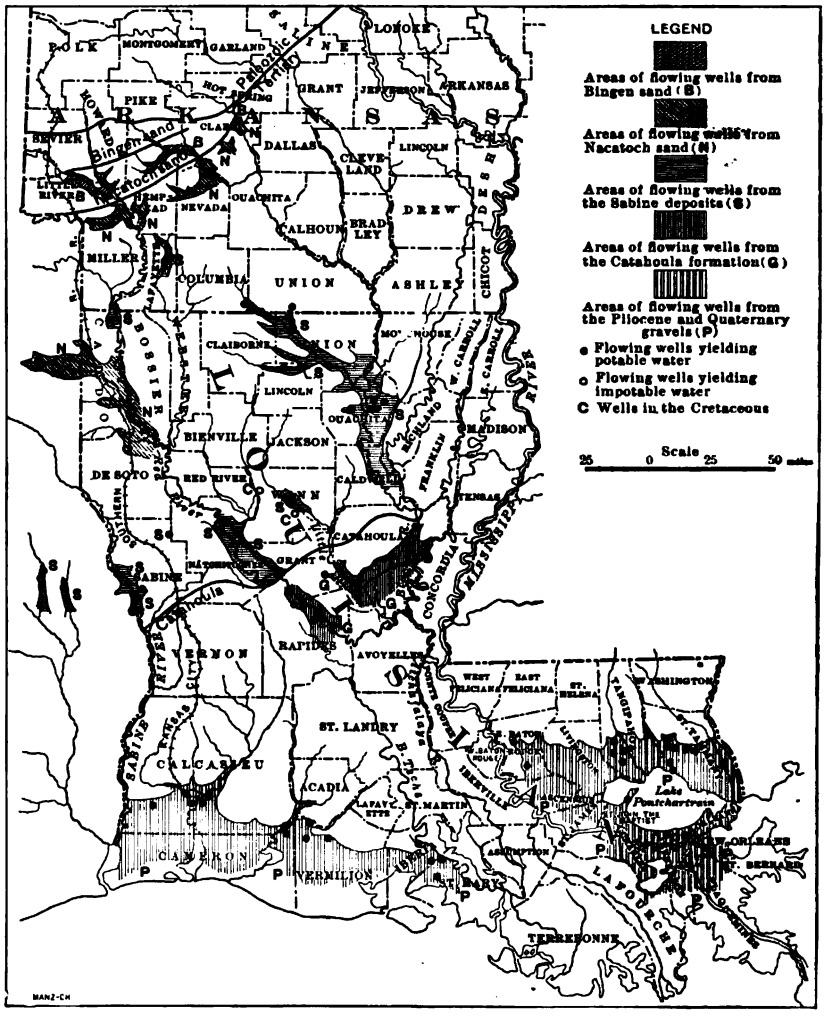


FIG. 25.—Artesian areas in Louisiana and southern Arkansas.

mile in a southeasterly direction, the wells get deeper to the south, and reach an extreme depth of 784 feet near Columbus, a little north of the outcrop of the Nacatoch sand. Some failures have been reported in the lower part of this territory, notably at Columbus and

[a] Name used by Hill for beds which he doubtfully referred to the Eocene. These, with the exception of a single Nacatoch outcrop which was incorrectly included in this series, are now known to pass beneath the Brownstown and to represent the littoral beds of the basal upper Cretaceous.

Washington, but they were due to the fact that the wells were abandoned before the required depth had been reached. The greatest development has naturally been in the region where flowing water can be obtained (fig. 25). The maximum depth to which wells will be driven in this region will probably not exceed 900 feet, as before this depth will become necessary the Nacatoch sands will appear on the surface, making good shallow wells possible.

The water is very soft and somewhat alkaline, except in wells which do not flow and have only been partially cased, and in which the water therefore stands in contact with the overlying calcareous clays. Hard water has been found in a few wells, as at Hudson and near Burtsell, but in these it seems to occur in the calcareous beds which overlie the Bingen sands, and the indications are that if the wells had been deepened 200 or 300 feet they would have reached the Bingen and obtained soft water.

Nacatoch sand[a].—This sand, like the Bingen, is of very great value to a large section in southern Arkansas, where it is practically the only available source of well water. In areas underlain by the Bingen and Nacatoch sands the surface formations are rich, calcareous clays, with here and there thin coatings of younger gravel, and the surface water is generally hard and very unsatisfactory. Persistent water-bearing horizons, which are so well understood that the depth to water can be predicted at any point and which will furnish soft artesian water over wide areas, can not fail to have a great effect on the development and land values of the regions which they underlie.

The Nacatoch sand has been extensively developed along the line of the Iron Mountain Railroad from west of Red River almost to Arkadelphia (fig. 24). It dips southeastward at a rate of from 50 to 100 feet per mile until it reaches a point about 800 feet below sea level, when it abruptly becomes horizontal and continues so to a point somewhat south of Shreveport, where it again slopes normally

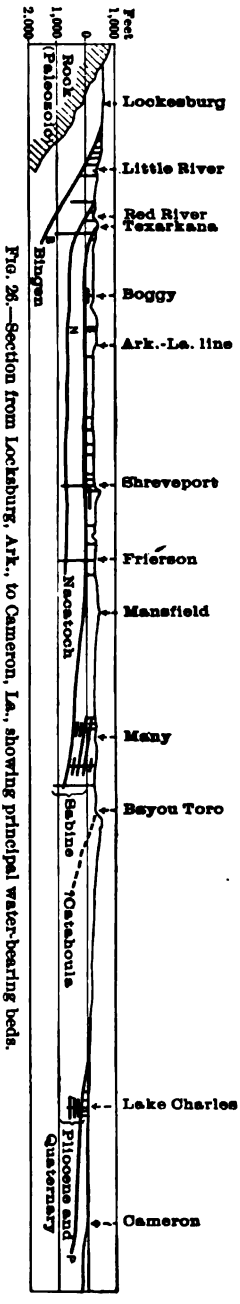


Fig. 26.—Section from Lockesburg, Ark., to Cameron, La., showing principal water-bearing beds.

[a] Name taken from typical exposure at Nacatoch Bluff on Little Missouri River in Clark County. This formation includes the sand beds between the Marlbrook and Arkadelphia which Hill included in his Washington or High Bluff greensands (Ann. Rept. Arkansas Geol. Survey for 1888, vol. 2, 1888, pp. 72-75, 188).

coastward (fig. 26). This extensive horizontal development would make this sand of great value over wide areas were it not for the fact that south of a line which runs irregularly from 3 to 15 miles from the outcrop the water is salty. Seemingly that portion of the sand near the outcrop has been thoroughly washed by percolating waters, while that less favorably situated is in its original salty condition, and the saltiness may even have been increased by matter washed down from the upper layers. Developments at Texarkana, Jefferson, Shreveport, and Frierson have yielded impotable water, which at the last three places is artesian, indicating an artesian basin covering a considerable part of the Red River Valley (fig. 25). The brine which occurs in some of the Cretaceous uplifts in northern Louisiana is likewise from this horizon. In general, it is felt that that portion of the sand which lies south of the area shown in fig. 24 will not furnish potable water.

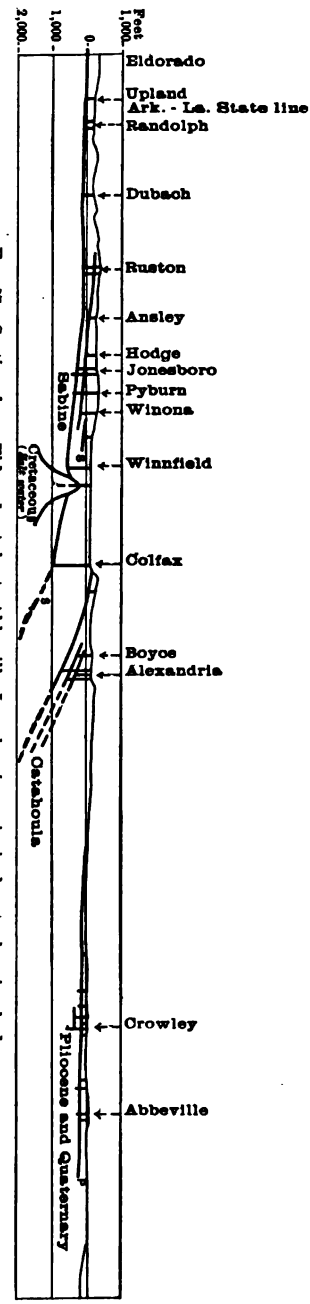


FIG. 27.—Section from Eldorado, Ark., to Abbeville, La., showing principal water-bearing beds.

Sabine group.—Under this head is classed not a single well-defined horizon like the Nacatoch, or Bingen, or other Cretaceous beds, but a number of somewhat irregular water sands occurring throughout a formation which, in the western part of this area attains a thickness of perhaps 1,000 feet. The lowest of these sands occurs about 700 feet above the Nacatoch, and like it, is very nearly horizontal over a considerable area (figs. 26, 27). Eastward and southward this bed dips gently toward the Mississippi Valley and the coast.

Other sand beds occur in the formation above this one, at varying distances from each other, and of varying thickness. Nine have been developed at Plymouth, La., and six at Ruston. These beds thin and thicken very rapidly, so that in one well a sand may be developed which in a nearby well is too thin to give results. Wells, then, show considerable irregularity in depth,

some wells developing one bed and some another; but in general the wells are deeper to the south and toward the Mississippi Valley, as in each case the dip carries the sands beneath younger beds, and it becomes necessary to pass through a certain thickness of overlying deposits even to reach the topmost water sands of this series.

The failures in the southern part of the territory, near Natchitoches and Luella, La., are due to the occurrence of salt water, which is doubtless traceable, in part, to the neighboring uplifts of the older Cretaceous beds. These beds generally carry artesian brines, and as they are often broken the brine leaks into the surrounding Sabine sands. In the region of these domes it is often possible to predict the position of a sand, but it is quite impossible to indicate the kind of water it will contain. It is believed that the sands which furnish brine at Luella and Natchitoches are a continuation of the sands which yield good water about Shreveport.

Cockfield beds.—Overlying the Sabine are the fossiliferous Claiborne beds, which have little water-bearing value. Above the fossiliferous Claiborne are the Cockfield beds, which contain near their base an important water-bearing horizon. In central Louisiana the deeper wells which penetrate this horizon, as those at Leland, Rochelle, Olla, Tullos, and Colfax, obtain impotable water, though an exception is to be noted in the case of the deep well at Robinsons Ferry on Sabine River, in which a soft, pleasant-tasting water is reported at a depth of 1,010 to 1,030 feet. Near the outcrop successful wells have been finished at Clarks in Catahoula Parish, and at Weavers Spur in Natchitoches Parish.

In southeastern Arkansas and northwestern Mississippi this horizon is very extensively developed and furnishes good supplies of soft alkaline water at depths of 400 to 500 feet below sea level.[a] Between it and the base of the Jackson in this region a number of water sands have been developed in different wells, but they show little regularity and the better wells have, almost without exception, been finished in the main horizon.

The outcrops of the Cockfield sands in Arkansas and Louisiana are all relatively low, and the water will generally not rise much above 100 feet above sea level. Flowing wells will be obtained along the main stream channels in central Louisiana. In Arkansas and northwestern Mississippi the artesian area is near the eastern side of the flood plain where a relatively higher head is developed, because of the greater average height of the Mississippi hill lands. Water will rise very near the surface over all the flood plain, but in Arkansas it is regarded as quite impossible that flowing wells will be obtained.

[a] The wells in Chicot, Drew, Bradley, Cleveland, and Jefferson counties, except the deep ones at Pine Bluff, which are incorrectly marked S in fig. 23, should be credited to this horizon.

Jackson beds.—Beds of this age generally furnish hard water, and are therefore not extensively developed.

Catahoula beds.[a]—The sands and sandstone of this formation are good water carriers, and have yielded excellent results in central Louisiana, where they furnish flowing wells at Zimmerman, Boyce, Alexandria, Pollock, and Harrisonburg. Several horizons have been developed which furnish soft water of a very good quality, and it is probable that over a considerable area along Ouachita and Black rivers and about Catahoula Lake and Little River (fig. 25) flowing water is to be expected from these sands. Flowing wells will doubtless be obtained in Sabine River Valley below the outcrop of the Catahoula, as indicated by the water obtained from these beds on the Angelina near Rockland, Tex.; but in the high hill region about Leesville the wells will probably be very deep, and the water will have to be pumped some distance.

Pliocene and Quaternary gravels.—These sands and gravels underlie a large portion of southern Louisiana, and should doubtless be regarded as the most important water horizon in the State. The outcrops on the hill lands are large, and therefore the amount of rainwater passing into them is great. Covered with the more recent coastal clays, they furnish artesian water over considerable areas (fig. 24), and over still larger areas (fig. 25) the water rises so near the surface that it is readily available for irrigation and other uses. In the Mississippi bottoms, and sometimes toward the coast, the water in these beds is generally so charged with various soluble salts that it is of little value. Under the main river valleys in northern Louisiana and southern Arkansas there are thick deposits of sand and gravel partially filling the old valleys. In this, limited supplies can be obtained from driven wells of no great depth, but when large supplies are needed wells should be pushed to the main gravel bed, which overlies the older Cretaceous and Tertiary strata. This can be reached at depths ranging from 75 to 150 feet.

MINERAL SPRINGS.

Although there are many small springs scattered throughout Louisiana, only three reported sales for 1902. These were as follows:

Abita Springs, Abita Springs, St. Tammany Parish.
Mandeville Springs, St. Tammany Parish.
Ozone Springs, Pearl River, St. Tammany Parish.

The total output was 499,261 gallons, with a value of $43,502.[b]

[a] Name proposed from typical development of formation in Catahoula Parish, La., used for the lower or typical Grand Gulf of Hilgard as exposed at Grand Gulf, Miss. This formation includes the sandstone-bearing clays between the Vicksburg and Fleming Oligocene.

[b] A. C. Peale, U. S. Geol. Survey, Mineral Waters, 1902.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 123–124.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, 1902, pp. 49–50.

Subterranean waters of Louisiana, by G. D. Harris: Louisiana Geol. Survey, Rept. for 1902, pp. 205–252.

Underground waters of southern Louisiana, by G. D. Harris and M. L. Fuller: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 101, 1904.

NORTHERN ARKANSAS.

By A. H. Purdue.

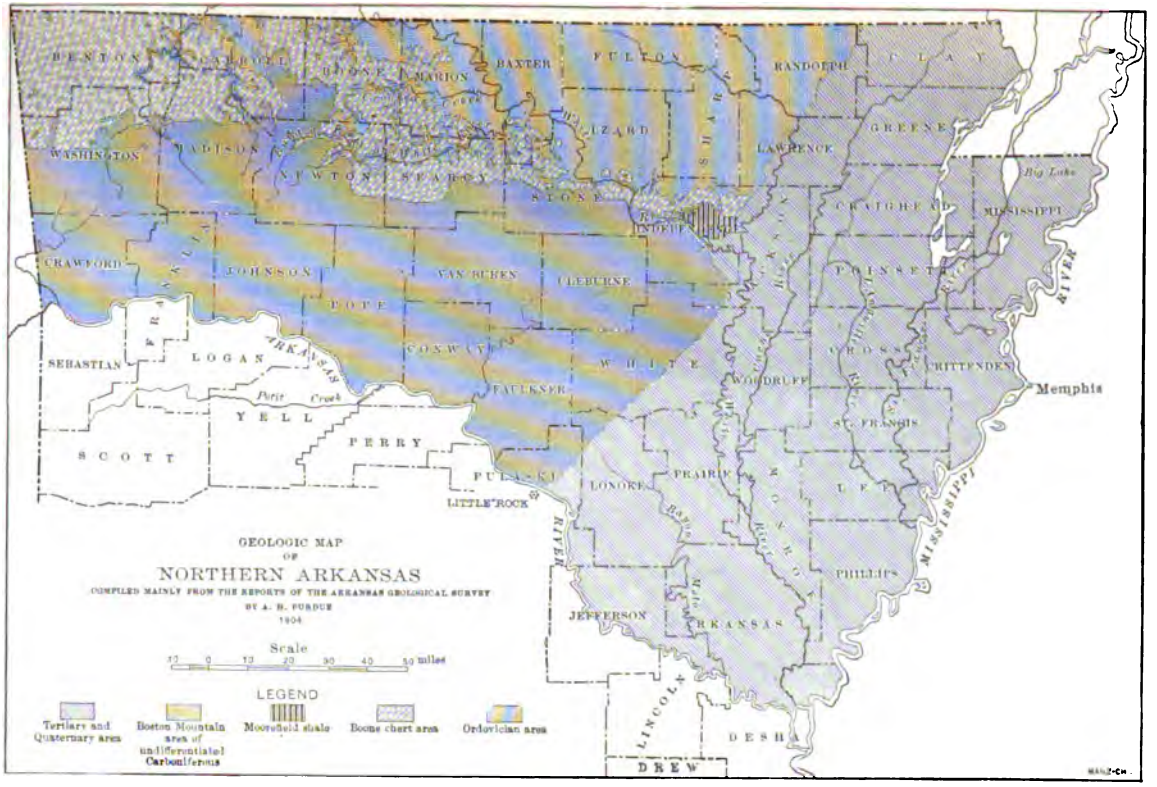
DESCRIPTION OF THE REGION.

That part of Arkansas lying north of Arkansas River comprises a little more than half of the area of the State, or about 28,700 square miles. Topographically it is divided into two well-defined areas—the eastern or lowland area and the western or highland area. The average elevation of the lowland area will probably not exceed 225 feet above sea level. The even, monotonous character of the surface is disturbed only by Crowleys Ridge, which extends northward from Mississippi River at Helena to St. Francis River at St. Francis, and into Missouri. This ridge is from 1 to 14 miles wide, and in its highest part is about 400 feet above sea level, or 180 feet above the adjacent lowlands.

The highlands are a part of the Ozark region and vary in altitude from less than 500 to 2,250 feet above sea level. They are divided into two parts, a northern and a southern, each of which is a plateau, much dissected by streams. The southern of these is the higher, and is known as the Boston Mountains. These mountains are highest in the western part of the State and gradually fall eastward, the elevation south of Batesville being 800 feet (aneroid). The Boston Mountains are separated from the lower plateau to the north by a more or less bold and irregular escarpment, the height of which varies from 500 to 1,000 feet. Figs. 28 and 29 supplement this description and aid in giving a general idea of the topography of the region.

RESOURCES.

Resources of the highlands.—The main resources of the highlands are its soil, timber, mineral deposits, and water supplies. While the really rich soil of this part of the State is confined mainly to the narrow flood plains of the valleys, much of the remainder yields fair returns, and practically all of it is well adapted to horticulture. All fruits suited to this latitude flourish. The high altitude, to which the healthful, genial climate is largely attributable, and the universal abundance of pure water have combined to make it a favorable place for settlement


GEOLOGIC MAP
OF
NORTHERN ARKANSAS
COMPILED MAINLY FROM THE REPORTS OF THE ARKANSAS GEOLOGICAL SURVEY
BY A. H. PURDUE
1904
Scale
10 0 10 20 30 40 50 miles
LEGEND
Tertiary and Quaternary area
Boston Mountain area of undifferentiated Carboniferous
Moorefield shale
Boone chert area
Ordovician area
BENTON
CARROLL
BOONE
MARION
BAXTER
FULTON
RANDOLPH
CLAY
WASHINGTON
MADISON
NEWTON
SEARCY
STONE
IZARD
SHARP
LAWRENCE
GREENE
INDEPENDENCE
CRAIGHEAD
MISSISSIPPI
CRAWFORD
JOHNSON
VAN BUREN
CLEBURNE
POINSETT
POPE
CONWAY
WHITE
CROSS
CRITTENDEN
SEBASTIAN
LOGAN
FAULKNER
WOODRUFF
Memphis
YELL
ST. FRANCIS
PERRY
SCOTT
PULASKI
LONOKE
PRAIRIE
LEE
LITTLE ROCK
PHILLIPS
JEFFERSON
ARKANSAS
LINCOLN
DESHA
DREW
Big Lake
Point Creek
ARKANSAS RIVER
MISSISSIPPI RIVER
WHITE RIVER
CACHE RIVER
BAYOU METO
BAYOU BOEUF
BAYOU BARTHE

since the early days of exploration. The rough topography has until recently prevented the extensive construction of railroads. At the present time, however, two important lines are being built and are in actual operation over a considerable part of their routes. The region contains large areas of practically undisturbed timber, fine in quality. In the northern part is a large area containing deposits of zinc ores. A thin vein of coal covers a portion of the central part of the region, and along the Arkansas Valley is an abundance of coal, which is being worked at many points. Among other mineral deposits are phosphate, manganese, building stones, and clays in great varieties.

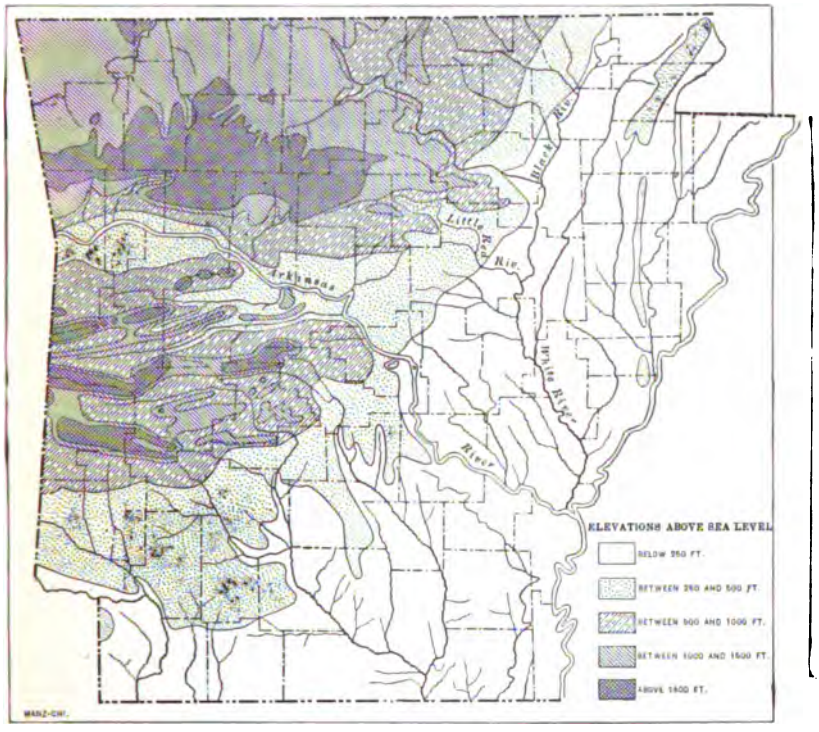


FIG. 28.—Relief map of Arkansas.

Resources of the lowlands.—The wealth of the lowland region is in its soil, timber, and waters. Much of the soil is of unusual fertility. While a great deal of the timber has been removed in recent years, a large amount still remains. As a rule, the population is densest along the river valleys, where the soil is richest, and where transportation was most easily secured in the early settlement of the State. Along Crowleys Ridge the principal towns are Helena, Marianna, Forrest City, Harrisburg, Jonesboro, and Paragould. The narrow strip of land along Arkansas River extending beyond the western border of the State is covered with flood-plain deposits, and should be considered a part of the lowlands.

GEOLOGY.

Geology of the plateau region.—The rocks of the plateau region are of Paleozoic age, and include the Ordovician, Silurian, Devonian, and Carboniferous. Ordovician rocks are exposed over a large area in the northeastern part of the division and farther west in Carroll County. They also occur along many of the stream valleys outside these areas. The rocks are of great thickness, and consist mainly of magnesian limestone, though there are a few beds of sandstone and shale.

The Silurian and Devonian rocks are exposed along the steep hillsides bordering the valleys. The Silurian consists of a limestone known as the St. Clair limestone,[a] and the Devonian of sandstone and shale known, respectively, as the Sylamore sandstone and the Eureka shale.

The Mississippian ("Lower Carboniferous") covers most of the northern division of the plateau area not occupied by the Ordovician, and consists of the Moorefield shale, the Boone chert, the Batesville sandstone, the Fayetteville shale, the Archimedes limestone, and probably some sandstone and shale above the last-named formation. The southern part of the highland area is occupied mainly by rocks of Pennsylvanian ("Upper Carboniferous") age, consisting of some limestone and a heavy deposit of sandstone and shale. The rocks are practically horizontal over the northern division of the plateau region, but from the Boston Mountains southward they fall off by monoclines and faults to the Arkansas River Valley. The structure of the southern part is not sufficiently well known to be shown in the section.

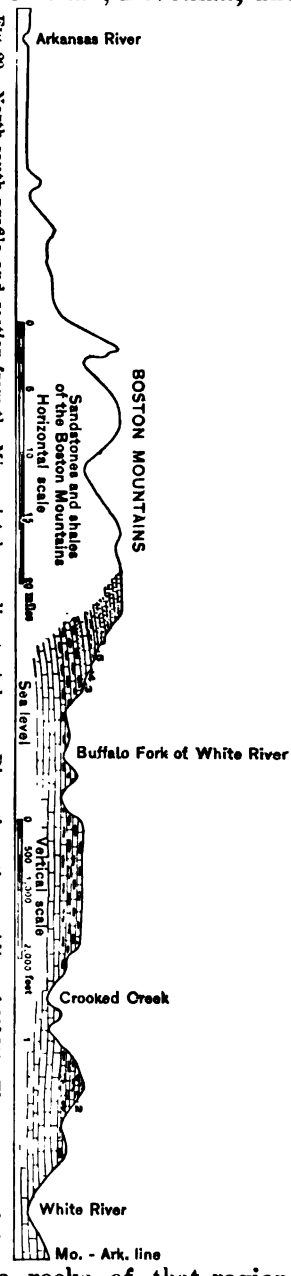


FIG. 29.—North-south profile and section from the Missouri-Arkansas line to Arkansas River, along the meridian of 92° 50'. The structure of the south half is uncertain. 1, Ordovician and Silurian; 2, Boone chert; 3, Batesville sandstone; 4, Archimedes limestone; 5, Pentremital limestone.

Geology of the lowlands.—With the exception of a sheet of alluvium over a large part of the lowland area the surface rocks of that region are of Tertiary age. They consist almost entirely of unindurated sand

[a] The geologic nomenclature herein used is that used by the late geological survey of Arkansas.

and clay, the sand greatly predominating. The thickness of this surface deposit increases rapidly from the highland border eastward. At Newport, according to the record of a deep well near that city, on a farm owned by Mr. W. B. Chastain, it is 655 feet, that being the distance below the surface at which the Paleozoic rock was encountered. East of this point the thickness is not known.

WATER RESOURCES.

There are two natural divisions of the area under consideration which can be made on the basis of their water supplies—the Paleozoic and the Tertiary.

PALEOZOIC REGION.

The horizontal position and diversified character of the rock over the northern part of this region make the hydrologic areas conform to the areas over which water-bearing rocks are exposed or to their lines of outcrop. A detailed geologic map of the region would at the same time be a hydrologic map. Some of the water-bearing strata are exposed over large areas, others outcrop in practically horizontal planes along the hillsides. As it is not possible to present herewith a detailed geologic map, the hydrology of the Paleozoic region will be discussed under the following heads, which are somewhat arbitrarily chosen: The Ordovician area, the Boone chert area, and the Boston Mountain area.

THE ORDOVICIAN AREA.

This occupies that part of the region under consideration over which the Ordovician rocks are exposed at the surface. As previously stated, these rocks consist mainly of magnesium limestone. From these rocks, where they are cut into by streams, emerge numerous strong springs. Among these is Mammoth Springs, in Fulton County, which is said to discharge 9,000 barrels of water per minute.[a] As would be expected, the water of this region is hard, owing to the presence of the salts of calcium and magnesium in solution. The rocks are compact, and as a result the water can move only through joints and other fissures. For this reason the wells secure water only in case they strike a fissure. Some wells furnish an abundance of water, others, failing to strike fissures, are dry. The uncertainty of finding water in wells and the hard nature of the water have caused frequent resort to cisterns.

The most common method of sinking wells is by blasting out the rocks, but drilling is sometimes resorted to. So far as the chances of

[a] Rept. Geol. Survey Arkansas, 1891, vol. 1, p. 65.

striking a fissure are increased by an increase of the well diameter, blasting is the most promising method. On the other hand, the chances for striking a fissure are greater in a deep well than in a shallow one, and as the cost of drilling a deep well is less than that of blasting, the former method is advisable in most cases. Especially is this true when the sanitary advantage of a well-cased drilled well over an open one is taken into consideration.

THE BOONE CHERT AREA.

The character, thickness, and wide outcrop of the Boone chert make it the most important water horizon in northern Arkansas. It is composed of limestone and numerous lenses of much-fractured chert. Beneath the Boone chert is a limestone from 25 to 50 feet thick, known as the St. Joe marble, but for hydrologic purposes the two may be considered together. Where not removed by denudation the Boone chert usually exceeds 300 feet in thickness. It is exposed over an area of about 3,600 square miles. Solution has removed the limestone from the upper part of the formation, but the chert, being insoluble, is left as a residue on the surface, in many places several inches thick. In such places this chert débris largely reduces the run-off from the rainfall, and by so much adds to the amount of water that enters the ground. The water descends through the joints in the limestone and is transmitted horizontally through the fractures in the chert lenses. Beneath the St Joe marble over a considerable portion of the area is the Eureka shale, which, being impervious, holds the water in the overlying limestone and chert. Along lines where streams have cut their valleys down to or beyond this bed of shale, springs with a copious flow of the best water are very numerous. Most of the famous springs at Eureka Springs emerge from this horizon.

In the western part of the State, over the Boone chert area, the divides between the streams are often flat, and in such cases water is easily secured by sinking wells a few feet, but in the eastern part, where the streams have cut far down into the Ordovician rocks and have left the Boone chert on the high divides between them, water is frequently below the level to which wells can be sunk by digging and blasting, the method usually employed. On account of the considerable depth of the water beneath these high divides the drill should be employed. By this method water could be obtained in most cases.

The water from the Boone chert, while hard, contains a smaller amount of matter in solution than might be expected, owing to the fact that so much of the formation is siliceous, and consequently insoluble.

THE BOSTON MOUNTAIN AREA.

There are several water-bearing horizons in what is here designated as the Boston Mountain area. Named in their order, beginning with the lowest, the most important are: The Batesville sandstone, the Archimedes limestone, and the Pentremital limestone.

Batesville sandstone.—The Batesville sandstone is usually brown, and consists of medium-sized grains. It is commonly in layers from 2 inches to 1 foot thick, but in some places the beds are more massive. In the eastern part of the Paleozoic area it exceeds 100 feet in thickness, but gradually thins out in the western part of the State, where in places it is altogether wanting. In the eastern part of the region it lies upon the Moorefield shale, but in the western part of the State this shale is absent, and the Batesville rests directly upon the Boone chert. Where near the surface and of considerable thickness, it forms an important water horizon, as about Green Forest, Carroll County, and at Batesville, Independence County. In both of these localities it furnishes excellent well water. At Batesville it was the chief source of water until waterworks were installed. As would be expected, the water from this horizon is soft.

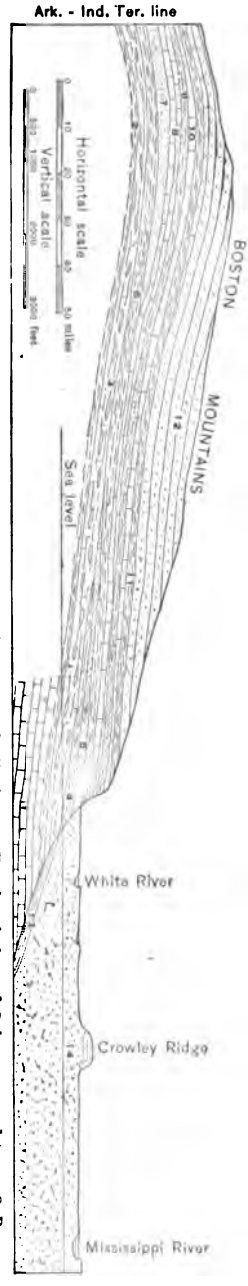


FIG. 30.—Generalized east-west section across northern Arkansas. 1, Ordivician and Silurian; 2, Eureka shale and Sylamore sandstone; 3, Boone chert and St. Joe marble; 4, Moorefield shale; 5, Batesville sandstone; 6, Fayetteville shale; 7, Wedington sandstone; 8, Archimedes limestone; 9, "Washington" sandstone and shale; 10, Pentremital limestone; 11, coal-bearing shale; 12, Millstone grit; 13, Cretaceous; 14, Tertiary.

Archimedes limestone.—The Archimedes limestone is a persistent formation, outcropping in an east-west direction across the Paleozoic area of the State, near the north base of the Boston Mountains. (See fig. 29.) In the eastern part of the region its thickness is 100 feet, but in the central and western parts it seldom exceeds one-fifth this amount. It is a compact limestone, composed largely of fossil remains. In places it contains lenses of chert, though these are not common. In the eastern and central parts of the area it rests upon the Fayetteville shale, a thick and impervious formation. In the western part of the State it is separated from the Fayetteville shale by the Wedington sandstone, which also contains some shale.

The massive nature of this limestone, which usually rests upon a bed of shale, causes it to form a conspicuous escarpment, from the base of which strong springs issue at frequent intervals. Below the escarpment, and upon the Fayetteville shale, is a bench from 100 yards to a quarter of a mile in width and of great fertility.

Pentremital limestone.—Above the Archimedes limestone (see fig. 29), and separated from it by a greater or less thickness of the "Washington" sandstone and shale, is the Pentremital limestone, which is also an important spring horizon, and which, like the one below it, is nearly everywhere productive along the north slope of the Boston Mountains. The water from both the last-named horizons is hard. Like most limestones, their texture is so compact that search for water in wells is not advisable.

The rocks at the tops of the Boston Mountains and of their outliers to the north are sandstone and shale. The sandstone varies in texture from medium-grained to coarse millstone grit. The porosity of the sandstone permits it to absorb a great deal of the rainfall, which is kept from sinking as underground water by the underlying impervious shale. As a consequence, the sandstones become important water-bearing strata, especially over the high, flat-topped table-lands between the heads of the mountain ravines. On these table-lands, water is easily secured from open wells. Springs frequently occur on the hill slopes, though they are neither so strong nor so numerous as along the Archimedes and Pentremital limestone horizons. Such springs are found over the large area covered by the Boston Mountains.

ARTESIAN CONDITIONS IN THE PALEOZOIC AREA.

In the lower plateau area the horizontal position of the strata precludes the possibility of obtaining flowing wells, unless it be in local and limited areas, but near the north base of the Boston Mountains, in places where the rocks dip to the south, there may be small areas where flowing wells could be secured, the Boone chert being the source of the water.

An inspection of fig. 29 will at once suggest the possibility of securing artesian water along the Arkansas Valley. The Boone chert, which is widely distributed over the northern part of the State, and forms an excellent collecting area and through which the underground water is readily transmitted, dips south with the rocks of the Boston Mountains. Though the southward extent of this formation is not known, its thickness of more than 300 feet north of the Boston Mountains is good reason for supposing that it reaches beyond the Arkansas Valley. Over the collecting area its height is from 500 to 1,000 feet above the land along Arkansas River. Over it lie the heavy deposits of Moorefield shale and Fayetteville shale. All the conditions are favorable to this formation, being the source of an abundance of artesian water in

the Arkansas Valley, provided there are not many faults with an east-west strike between the Arkansas Valley and the catchment area. But it is known that faulting of the nature mentioned occurs here, and it is not improbable that it is sufficient to entirely cut off the southern flow of the water, thus destroying what would otherwise be excellent artesian conditions.

TERTIARY REGION.

The underground water of the lowland or Tertiary area has its source largely, probably mainly, in the rainfall of the region. The level surface holds the run-off in check, and sandy deposits take up a large amount of rain water, which is readily transmitted to all parts of its mass. Another source of water, unquestionably of great importance, is found in the streams which flow from the plateau region over the lowlands. When these streams are at low-water stage, the underground water moves slowly toward them from either direction. But when they are at flood stage, there is a large amount of leakage through the banks and into the loose, sandy material, for considerable distances in either direction away from the streams. The amount of underground water thus supplied to the lowlands from the Arkansas River, Little Red River, White River, Black River, and their tributaries, is problematical, but considerable. Another source of the underground water of this region is in the truncated edges of the Paleozoic rocks, beneath the younger deposits.

Owing to the low altitude, the uniformly level surface, and unindurated condition of the sediments, mainly sand, over the Tertiary area, an abundance of water can be secured almost anywhere by the expenditure of the small sum necessary to purchase from 10 to 40 feet of iron pipe, a point, a pump, and the few hours labor necessary to drive a well. The pump is usually of the kind known as the "pitcher pump," and the pipe is usually one and a quarter inches in diameter, sometimes common iron, sometimes galvanized. Because of the interlocking beds of sand and clay that in many places constitute the sediments near the surface, the depth at which water can be secured is uncertain, but it is seldom more than 40 feet. The water is most commonly raised by hand, though windmills are sometimes employed.

Formerly dug wells were the only source of water, and some of these are still in use, but they are rapidly being succeeded by driven wells. Bored wells are common in some localities. In a few instances these bored wells are cased with tile, carefully cemented at the joints to keep out the surface water, but wood is commonly employed for casing, a custom to be deprecated, as the decaying wood not only renders the water insanitary but permits the surface water to enter the well. Water for cities and ice plants is secured from bored wells 100 feet or more in depth.

The amount of water that can be supplied by almost any well is limited only by the capacity of the pipe. In cases where a large amount is needed, as for boilers of large capacity, either a pipe of sufficient diameter is used or the number of wells is increased till the desired amount of water is secured. As a rule, the water is fairly well suited for boiler use, but in some cases it forms a troublesome scale, produced by the combined deposit of the mineral matter in solution and the fine material in suspension.

The character of the water varies greatly both with depth and horizontal distance. As regards the depth to which wells should be extended, no rule can be laid down except the general one that the deeper the well the better the water. This, however, is not by any means always true, for shallow wells often furnish better water than near-by deeper ones, as where the shallow wells are wholly in a surficial deposit of sand, while the deeper ones pass into mud, which contains a great deal of organic matter and salts of iron in solution. Frequently two wells of the same depth and only a few rods apart furnish water of an entirely different character. That of one may be of good quality, while that of the other is wholly impotable. This is because near the surface there are horizontal variations in the character of the material, there being frequently intercalated deposits of mud containing a great deal of organic matter.

ARTESIAN CONDITIONS IN THE TERTIARY AREA.

The very small difference in altitude between the highest and lowest parts of this area would seem to preclude the possibility of securing artesian water in the Tertiary area, even though all the other conditions were favorable. In this area a well would probably have to pass through the Tertiary and into the Paleozoic rocks below. While the securing of artesian water from the Paleozoic horizon appears to be possible, the chances are against success. The southward dip of the Paleozoic rocks would bring these beds, if continuous, under the Tertiary deposits, in which case the chances of securing artesian water from them would be excellent. But those beds are truncated along the Tertiary-Paleozoic border to considerable depths (see fig. 30), permitting the water to leak into the younger rocks. Besides, the east-west faulting of the Paleozoic rocks, probably cutting off the southward flow of the water, would be effective over the lowlands.

MINERAL SPRINGS.

The large springs of the limestone districts of the Paleozoic area have already been mentioned. Besides these there are a multitude of smaller springs, many of which yield mineral water of value for medicinal or domestic purposes. A considerable number of them have

been developed as resorts, some of which are among the most important in the country. Sanitariums using spring water are common. The waters are generally used at the spring, but in 1902 seven springs reported sales amounting to 149,100 gallons, with a value of $52,575. The springs reporting are as follows:[a]

Allen's Alterative Magnesia Spring, Hot Springs, Garland County.
Arkansas Lithia Springs, near Hope, Hempstead County.
Arsenic Spring, Hot Springs, Garland County.
Blanco Springs, near Hot Springs, Garland County.
Eureka Springs, Eureka Springs, Carroll County.
Potash Sulphur Spring, near Hot Springs, Garland County.
Ravenden Springs, Ravenden Springs, Randolph County.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 118–122.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, p. 12.

Arkansas [well and spring records], by A. H. Purdue: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, pp. 374–388.

Summary of the water supply of the Ozark region in northern Arkansas, by G. I. Adams: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, pp. 179–182.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

TENNESSEE AND KENTUCKY.

By L. C. Glenn.

TENNESSEE.

Topography.—In crossing Tennessee from east to west the following topographic divisions may be recognized: (1) The Valley of East Tennessee, (2) the Cumberland Plateau, (3) the Highland Rim or Plain within which the Nashville basin has been eroded, (4) the Western Valley of Tennessee River, (5) the Gulf Coastal Plain, and (6) the Mississippi Alluvial Plain or Bottoms.

Rainfall.—The rainfall is between 50 and 60 inches annually. In autumn, the driest season, it is 2 or 3 inches less than the average, and in winter, the wettest season, it is 2 or 3 inches more than the average; in spring it is slightly more and in summer slightly less than the average.

VALLEY OF EAST TENNESSEE.

Description.—The so-called Valley of East Tennessee is that part of the great Appalachian Valley that extends southwestward across the eastern end of the State from the Virginia to the Georgia line. Its width varies from 45 to 60 miles. It is limited on the southeast by the Great Smoky Mountains along the North Carolina line, and on the northwest by the eastern scarp of the Cumberland Plateau. The floor of this valley has an elevation of 900 feet at Chattanooga and of 2,000 feet along the Virginia line. Many long, narrow, parallel ridges trending northeast-southwest in the same direction as the valley itself rise above its floor. They are separated by long, narrow, minor valleys. The ridges are formed by the hard, upturned, folded and faulted Cambrian, Silurian, and Devonian rocks, while the intervening valleys have been eroded in the limestone or soft shale.

Water resources.—Along the eastern side of the valley the Great Smoky Range, which reaches an extreme height of over 6,500 feet, is carved along with its projecting spurs either from metamorphosed sediments of probably Cambrian age or from more ancient igneous rocks of various kinds. Among these spurs many bold freestone springs are found, and every ravine has its streamlet of pure, clear,

and unfailing water. The region is rough and sparsely settled, and the springs furnish an abundant and satisfactory water supply.

In the valley proper the streams are usually broad, shallow, and rapid. Their waters are generally pure and clear, except after heavy rains. Innumerable springs are found throughout the valley. Because of the great variety in the rocks of the region the water of the springs varies greatly in character. From the limestones and dolomites large and bold springs of clear, hard but wholesome, water issue constituting the most common supply for household purposes. The waters often contain magnesian salts where the springs issue from the Knox dolomite. In general it may be said that their chief mineral contents are calcium, magnesium, and sodium carbonates, sulphates and chlorides, with occasionally iron sulphate and carbonate or aluminum sulphate or alum. Many sulphur, iron, and alum springs are found in the Devonian black shale. Sulphur waters are also found in the limestones and dolomites. Chalybeate waters occur in the sandstones and conglomerates, though freestone waters are more common. In several counties Epsom springs are known.

Some of these valley springs have earned a wide reputation for their medicinal qualities, and annually attract many visitors in search of health, recreation, or rest. A few ship their waters.

In some cases these natural supplies are supplemented by cisterns, though the abundance of springs and their unfailing flow, no doubt largely due to the faulting of the rocks, render the use of cisterns less necessary than in many limestone regions. In those towns which are without a system of waterworks the use of cisterns is more prevalent, as they furnish the only safe water supply under such conditions. In the larger cities water supplies are obtained from near by rivers or other smaller streams. Although the valley is well settled the population is largely agricultural and scattered, and stream supplies may be regarded as safe except where contaminated by tan bark, wood pulp, or other similar industries.

CUMBERLAND PLATEAU.

Description.—The Cumberland Plateau crosses Tennessee in a northeast-southwest direction, and varies in width from about 35 miles near the Alabama line to about 50 miles near the Kentucky line. Its elevation is 1,500 feet on the Alabama line, 2,000 feet in the center of the State, and 3,500 feet near Cumberland Gap. The plateau surface stands about 1,000 feet above the adjacent regions on either side. The eastern edge is an abrupt scarp that is straight for miles. The western edge is an equally abrupt scarp, but is notched by the headwaters of streams that have eaten into the plateau from the west. The surface, while measurably flat, is diversified by shallow valleys and low ridges.

Water resources.—The rocks of the plateau are of Carboniferous age. Much of the surface is underlain by sandstone, which forms an open porous soil if well drained. From this sandstone issue the numerous freestone springs that furnish so large a part of the water supply of the region. During summer and fall droughts sometimes occur, and many springs and streams decrease in volume or go entirely dry, so that water for household use and for stock becomes scarce while the small mills for grinding corn remain idle until rains set in. Open wells supplement the springs in many instances.

Supplies of water may be obtained by drilling a few hundred feet into the thick sandstone beds that underlie the larger part of the plateau. Such waters will not usually flow, but will rise within easy pumping distance of the surface. They may contain more or less iron from the sandstones or sulphur from the interbedded shales and coals. Wells drilled deeper into the underlying Mississippian or Silurian limestones or into the Devonian black shale usually obtain salt water, with greater or less amounts of natural gas or petroleum.

There are numerous chalybeate springs on the plateau, some of which are of local repute as summer resorts. Although none have been improved to any extent, the clear, cold, freestone waters, combined with the elevation and delightful summer temperature, bring many visitors from the lowlands during the heated season.

Much of the plateau is underlain by workable coal and mines are being opened at numerous places, each of which becomes the nucleus for the development of a mining town. With its growth the quality of its water supply, usually taken from open wells and springs, will deteriorate.

HIGHLAND PLAIN.

West of the Cumberland Plateau lies the Highland Plain, which extends westward to Tennessee River. The width of this plain is about 175 miles along the Kentucky line and 105 miles along the Alabama line. Its average elevation is approximately 1,000 feet. Viewed broadly, its surface is level; viewed in detail, it is gently undulating or cut by small streams into narrow but sometimes steep-sided valleys. In a few places the larger rivers, including the Cumberland, Duck, and Elk, have cut steep-walled valleys 300 or 400 feet deep and have eroded out of the very center of the Highland Plain a great oval basin 120 miles long and 50 broad, whose comparatively flat bottom is 300 to 400 feet below the encircling plain. This basin is known as the Nashville or Central basin and will be discussed in a subsequent paragraph.

PLATEAU REGION.

Description.—The siliceous beds of the Mississippian form the surface of the Highland Plain. These beds consist of limestones, siliceous

shales, and chert. As they form the surface of this plain they have been exposed to the leaching action of the water so long that the calcareous matter has been removed to a considerable depth and the surface is a disintegrated mass of reddish clay and porous chert.

Water resources.—The waters of the Highland Plain are mostly of he clear freestone type, although some are chalybeate from the iron contained in the chert. Where the lime has not yet been entirely leached from the rocks the waters may be hard. Many springs are found on the Highland, although in numerous areas springs are weak or wanting, or fail during dry seasons. Many of the smaller streams dry up also. In such places deep drilling generally gives a water containing objectionable quantities of calcium and magnesium carbonates and sulphates, hence the main dependence for potable water in such cases must be cisterns, of which many are in use.

Along the eastern margin of the Highland Plain at the foot of the escarpment which rises to the Cumberland Plateau many very large springs flow from the outcrop of the flat-lying Mississippian limestones underlying the sandstones of the plateau. These limestones receive a considerable part of the drainage which emerges along the edge of the Highland Plain in streams, many of which are large enough to turn a mill where they issue from their underground channels.

In the portion of the Highland area adjacent to the central basin are many sulphur springs, while on the steep slopes between the two the springs from the outcropping black Devonian shale contain sulphur, iron, and in some cases alum. No extensive area of this slope is made up of black shale, however, as it varies from only a few feet to 20 or 30 feet in thickness. Some of the sulphur and other mineral springs on the Highland and on the slope into the basin have beeen improved and have considerable reputation as summer resorts.

NASHVILLE BASIN.

Description.—The strata of the central portion of the Highland Plain have been arched into a low oblong dome which Elk, Duck, and Cumberland rivers have eroded until they have cut through the Mississippian and Devonian and into the softer limestones and shales of the Silurian. These have been in turn eroded, resulting in the undermining of the overlying rocks of the Highland Plain and the final formation of a basin of the dimensions already given. The bottom of this basin is flat or gently rolling. It slopes somewhat toward the Cumberland and other main streams and has some isolated knobs that rise to nearly the height of the adjacent Highland, while from the rim spurs project into the basin.

Water resources.—The Silurian limestones that form the floor of the Nashville basin dip away from its center in all directions, but at such

a low angle that they appear nearly flat. Many springs are found in these limestones, some of them being very large. They furnish clear, cold, hard water as a rule, though some of them contain sulphur. During the dry seasons many of the weaker springs and smaller streams go dry and difficulty is found in securing water supplies. Cisterns are extensively used, especially for household purposes, while ponds are dug or small streams dammed to secure water for stock. This region is the most fertile and most thickly populated in the State. Some cities, such as Nashville, get their water supply from rivers, others obtain water from deep wells which are pumped, while others without waterworks depend mainly on cisterns.

No persistent horizon of potable deep waters is known to underlie the basin surface. Water may be obtained almost anywhere by drilling a few hundred feet, but it is usually strongly impregnated with sulphur or is salty. In the lowest part of the basin the deep wells may flow. Several of the deep wells in Nashville are strongly sulphurous. Wells in other parts of the basin sometimes give off small quantities of natural gas, or are greatly injured by a slight exudation of petroleum. Many other wells, especially if not deep, furnish good water.

WESTERN VALLEY OF TENNESSEE RIVER.

The Highland Plain is bounded on the west by the western valley of Tennessee River, a north-south valley 400 to 600 feet deep and 8 or 10 miles wide. The rocks making the floor and most of the walls of the valley are Silurian limestones and shales, though Devonian, Mississippian, or even Cretaceous and Lafayette may in places form part of the wall. Iron and sulphur springs are numerous along the outer edges of the valley floor and in several places wells drilled years ago for salt yield an abundant flow of sulphur water, which is said to possess valuable medicinal qualities.

GULF COASTAL PLAIN.

Description.—The Gulf Coastal Plain extends from the Tennessee Valley westward to the bluffs overlooking the Mississippi River flood plain. Its width along the Kentucky line is about 65 miles; along the Mississippi line it is 105 miles. From an elevation of 600 to 800 feet in its southeastern portion its surface slopes west and northwest to an elevation of 270 feet at Memphis, and from 300 to 400 feet in the central and northwestern part of the area and along most of the bluff north of Memphis. The rocks of the region are unconsolidated sands and clays dipping gently westward, their lowest members outcropping in a narrow north-south belt just west of Tennessee River. The topography of the sandy formations is usually rolling to hilly, while

that of the clays and loams is often flat when remote from streams, but hilly when near them.

Geology and water supply.—The oldest rocks of this region are the Coffee sands of Cretaceous age. They outcrop in a belt that has an average width of perhaps 4 miles and extends northward from Mississippi halfway across the State along the eastern edge of the Coastal Plain region. They overlap the Paleozoic rocks exposed in the western valley of the Tennessee. The best exposure is at Coffee Landing, on the Tennessee, where they consist of fine micaceous sands and thinly laminated dark clays with abundant lignitic material. Their base is not exposed here, but slightly over 200 feet were seen. The total thickness can not be much more than this. Westward they dip under the Rotten limestone, which is also of Cretaceous age. This latter consists of green sand and fine-grained joint clay of a leaden color and often contains an abundance of fossil shells. It forms a belt 8 or 10 miles wide extending northward from Mississippi; also halfway across the State. Its maximum thickness, 350 feet, is found along the Mississippi line, but it thins rapidly northward. The water obtained from springs and wells is in most places hard and disagreeable in taste and odor. Good water may be obtained, however, by going through it into the Coffee sand. Many such wells exist. They vary in depth according to location, the deepest being about 350 feet. Water rises nearly to the surface as soon as the Coffee sand is reached and is generally of good quality.

Next westward is a belt of sands and clays, which where they enter from Mississippi are 12 to 15 miles wide, but only about 6 miles wide where they pass into Kentucky. They are known as the Ripley beds, are of Cretaceous age, and dip gently westward. Their thickness is perhaps 400 to 600 feet. Their surface is usually hilly. They are water bearers, but open wells may go 80 to 100 feet deep for water, though in lower ground 40 to 60 feet is a common depth.

Above the sands and clays of the Ripley beds, the latest of the Cretaceous formations, lies the Porters Creek (Flatwoods) clay. This clay is of early Eocene age, and consists of light, leaden-gray clays, with occasional laminæ of fine micaceous sand. The lower part contains beds of micaceous sand, greensand, and some thin impure limestones. The formation probably has an average thickness of more than 200 feet, and extends from Mississippi northward across the State in a belt 5 or 6 miles wide. The water derived from it is not of good quality. Better water may be had by going through it and into the underlying Ripley sands.

The "Lignitic" group rests on the Porters Creek formation and extends westward across two-thirds of western Tennessee to the bluffs overlying the Mississippi. It is composed chiefly of sands, in which

occur, especially in the eastern part of the area of outcrop, numerous lenses of plastic clays. In the western part of its area the upper part of the "Lignitic" is frequently marked by a bed of blue or dark lignitic clay about 150 feet thick. The total thickness of the "Lignitic" is 750 feet at Memphis. Its sands are water bearing throughout, but as they vary much and rapidly in coarseness, and consequently in quantity of water they can furnish, the proper depth of wells sunk into them must be determined by trial. Usually their lower part is the coarser, and the quality of the water yielded is generally suitable for any desired purpose. This group is by far the most valuable water-bearer in western Tennessee.

The Lafayette is spread as a thin blanket over all the preceding western Tennessee formations. It is a series of sands, clays, and gravels that are prevailingly red or orange in color and usually hardened, while in some places the sands have become cemented by iron into sandstones. The beds probably never exceed 50 feet in thickness and are more frequently less than 20 feet thick. Along the Tennessee and Mississippi River bluffs this formation consists very largely of gravel, while away from the neighborhood of these streams the gravel beds are thin or often wanting. When underlain by clays water is usually found at the base of the Lafayette. Along such of the stream valleys as cut through it numerous springs issue from these basal beds, while shallow wells may reach it anywhere. The water is usually good, provided the well is stopped in the Lafayette sand, but if it enters the top of an underlying clay or marl bed it is often poor. Over most of the region, however, the Lafayette rests on the "Lignitic" sands, and its base is then only locally water bearing, one well obtaining water while another only a few yards away may find none.

Loess overlies the Lafayette gravel in a belt 12 to 25 miles wide, extending north and south across the State. The thickness gradually decreases from 20 to 70 feet in the bluffs overlooking Mississippi River to an indefinite feather edge to the east. The loess is everywhere calcareous and wells sunk in it yield hard water. It naturally forms a rich soil and population is denser in this belt than elsewhere in western Tennessee. Many people in the loess region use cisterns, which are easily and cheaply constructed in the loess. Water of better quality may be obtained by deeper wells, drawing their supplies from the underlying sands of the "Lignitic."

Resting on the loess, and at times separable from it only with difficulty, or lying east of the loess belt and resting on the Lafayette, is a veneer of loam, clay, or sand that reaches in places perhaps 10 feet in thickness. It has generally been correlated with the Columbia. It is not of importance as a water-bearer.

MISSISSIPPI ALLUVIAL PLAIN.

In the flood plain of the Mississippi River the deposits are recent silts. These contain water at slight depths, but it is of poor quality. Its level rises and falls with the varying stages of the river. Good water may be obtained from the underlying lignitic by deep boring. Cisterns are also used, though the soft alluvial deposits are not always solid enough to prevent the walls of the cisterns from cracking.

COMMERCIAL SPRINGS.

The following springs reported sales of water in the year 1902:[a]

Eastbrook Springs, Eastbrook, Franklin County.
Hinson Springs, Hinson Springs, Henderson County.
Horn Mineral Springs, Horn Springs, Wilson County.
Idaho Springs, near Clarksville, Montgomery County.
Larkins Spring, Madison, Davidson County.
Lockeland Spring, East Nashville, Davidson County.
Montvale Spring, Montvale, Blount County.
Red Boiling Springs, Red Boiling Springs, Macon County.
Rhea Springs, Rhea Springs, Rhea County.
Tate Epsom Spring, Tate Spring, Grainger County.
Whittle Springs, Whittle Springs, near Knoxville, Knox County.
Willow Brook Spring, Craggie Hope, Cheatham County.
Wright's Epsom Lithia Well, Mooresburg, Hawkins County.

The aggregate amount sold is stated as 247,429 gallons, valued at $36,315.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 97-106.
Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, p. 49.
Tennessee [well records and spring records], by L. C. Glenn: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, pp. 358-367.

KENTUCKY.

Climatic conditions in Kentucky are much the same as in Tennessee. The topographic belts which are found in Tennessee extend northward into Kentucky, and the geologic formations of the two States are very similar. The water resources of Kentucky accordingly resemble those of Tennessee in corresponding topographic regions, so that much already said concerning the hydrographic characteristics of these belts in Tennessee applies equally well to Kentucky.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

CUMBERLAND PLATEAU.

The most eastern topographic division of Kentucky is the northward continuation of the Cumberland Plateau region of Tennessee. In Kentucky the flatness of the plateau surface, however, has disappeared, and in its stead the region is deeply dissected by streams, so that the actual surface consists of a maze of steep-sided mountains separated by almost equally narrow, steep-walled valleys. The plateau surface is represented only by the uniform altitude of the mountain crests. The southeastern edge of the plateau has an elevation of 3,500 feet, and is sharply defined by the Cumberland Mountain scarp. The western edge of the plateau has an elevation of 1,500 feet in the south, and of 900 feet along Ohio River. In Kentucky the plateau is not sharply defined on the west, but falls away in isolated projecting spurs of irregular but not great height, extending out toward the next and lower topographic division, the Lexington Plain.

The rocks of the plateau are horizontal Carboniferous sandstones and shales. Springs abound, and while in dry summers many of them, and even the smaller streams, dry up, there is generally an adequate supply of water. Some shallow open wells are used, but they furnish an insignificant part of the water supply. Some of the springs, especially such as flow from coal horizons, contain iron or sulphur. These may also at times contain alum. Population is sparse, houses are well scattered, and the springs are usually safe and wholesome. Even the simplest of sanitary precautions are, as a rule, unheard of, and occasionally water is used from a pool or branch that is utterly unfit for drinking, and doubtless the cause of a considerable amount of sickness.

LEXINGTON PLAIN.

The Highland Plain of Tennessee extends northward into Kentucky, where it is known as the Lexington Plain. In detail its elevation varies considerably but it may be taken as averaging 1,000 feet in its eastern and central parts and 800, 600, or even 400 feet along Ohio River. The surface of much of this Lexington Plain is composed of Mississippian and Devonian sandstones, shales, and limestones.

In sandstone regions the water is usually soft, and springs are more abundant and constant than in the shale or limestone areas. In the Devonian black shale, sulphur, alum, and copperas springs are often found. In the limestone areas much of the drainage is underground, and at many places big springs occur, some of which are so large that they furnish an abundant supply of water for good-sized towns. Such waters are hard.

In the north-central portion of this Lexington Plain there is an oval-shaped area of 10,000 square miles with Frankfort almost in its center that is composed of Silurian limestones similar to those of the Nash-

ville basin. Much of the drainage is underground, the water is hard, and springs are scarce in some portions. Water may be obtained by drilling generally at very moderate depths but it almost always smells slightly of petroleum or contains salt or other mineral matters rendering it unfit for domestic purposes. Streams dry up in the summer and ponds are dug to hold water for stock. Cisterns are very largely used.

Numerous mineral springs are found in the limestone region, some of which are noted health and summer resorts. They usually contain sulphur, iron, salt, or calcium and magnesium carbonate and sulphate.

In western Kentucky, on either side of the lower part of Green River, Carboniferous sandstones and shales are exposed in an oval area of 4,000 square miles which belongs topographically to the Lexington Plain but whose water supplies are in general much like those of the Cumberland Plateau region. Stream cutting has not been so deep as in the eastern part of the State and springs are somewhat less abundant, although sulphur and iron springs are numerous.

GULF COASTAL PLAIN.

That part of Kentucky which lies west of Tennessee River is known as the Jackson Purchase region. It is an area of unconsolidated sands and clays belonging to the Gulf Coastal Plain and forming a continuation of the similar area in western Tennessee.

Of the Cretaceous formations of Tennessee only the youngest, the Ripley, extends north into Kentucky. The Ripley sands and clays lie within 3 or 4 miles of Tennessee River and form a belt 5 to 10 miles wide. The formation is porous and open and becomes very dry during summer, so that open wells must frequently be sunk to a depth of 80 to 100 feet to insure adequate supplies. Cisterns and artificial ponds are extensively used. On the west the Ripley formation dips beneath the Porters Creek (Flatwoods) clay (basal Eocene), which gives more of a flatwood aspect to the topography here than it does in Tennessee. As in Tennessee, the water found in it is hard, "flat tasted," and not abundant. The thickness of the Porters Creek clay in Kentucky is not known, but it is probably not over 200 feet. It forms the surface in a belt 5 to 15 miles wide. Better water could be obtained in this area from the underlying Ripley sands, but the water probably would not flow except in very low places, though it would commonly rise nearly to the surface.

The western three-fifths of the Purchase region is composed of "Lignitic" sands and clays in which the coarser sand beds are water bearing. They are of variable character, however, and no one coarse stratum seems widely persistent. In the eastern part of the "Lignitic" area good water should be found within 200 to 300 feet of the surface. At Mayfield, for example, excellent water is obtained at a depth of 250

feet. Near Mississippi River the depth will increase to 500, 600, or 700 feet, and the sands tend to become finer and less reliable as water bearers.

Lafayette sand and gravel, loess, Columbia loam, and Mississippi flood-plain alluvium all occur very much as they do in Tennessee, and bear similar relations to water-supply problems.

COMMERCIAL SPRINGS.

The following springs reported shipments of water in 1902:[a]

Anita Spring, Lagrange, Oldham County.
Bedford Springs, Bedford, Trimble County.
Bluelick Springs, Bluelick Springs, Nicholas County.
Crab Orchard Springs, Crab Orchard, Lincoln County.
Upper Bluelick Springs, Nicholas County.

The aggregate sales are given as 169,750 gallons, valued at $21,537.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 106–118.

Preliminary list of deep borings in the United States, Pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 47–49.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

MISSOURI.

By Edward M. Shepard.

GENERAL CONDITIONS.

Missouri has an abundant supply of potable waters, which, for the most part, come to the surface in springs generously scattered over a large portion of the southern half of the State, and to a less degree over the northern half.

North of Missouri River the country is covered by glacial drift, varying from a few feet to 150 feet in thickness. In this area the springs are small, but they occur frequently where erosion has cut into the drift, which thus becomes the main reservoir for the wells and springs of the region.

South of Missouri River the country is destitute of drift, but erosion has cut deep valleys along the borders of the Ozark Plateau, and in such localities some of the largest and finest springs of the country abound.

TOPOGRAPHY.

Topographically, Missouri may be naturally divided into four great districts: (1) the Northwest Plateau, (2) the North-Central Plain, (3) the Ozark-St. Francis Dome, and (4) the Southeastern Lowlands, all of which are outlined on fig. 33.

The first district, the Northwest Plateau, includes the elevated portion in the northwestern third of the State, and is bounded on the southeast by the 900-foot contour. This plateau rises gently to the northeast corner of the State, where an elevation of over 1,200 feet is reached. The strata generally dip from 10 to 15 feet to the mile, in a northwesterly direction, thus burying to a considerable depth the Coal Measures which outcrop on the southern border of the district.

The south boundary of the second division, or the North-Central Plain, starts arbitrarily on Mississippi River in St. Charles County, runs southwesterly until it joins the north boundary of the Ozark-St. Francis Dome (at approximately the 900-foot contour) in Franklin County, which it follows to the northwest corner of Barton County on the Kansas line.

The Ozark-St. Francis Dome district is included in the large area between the last-described line and a line extending southwest from

Cape Girardeau to the Arkansas boundary, following the 400-foot contour.

The Southeastern Lowlands include the southeastern corner of the State south of the 400-foot contour, and nowhere have an altitude much exceeding 400 feet.

GEOLOGIC CONDITIONS.

The Northwest Plateau is covered wholly by drift, which is underlain by the Lower and Upper Coal Measures. The North-Central Plain is partially covered by drift in the northeast, and underlain by Mississippian and Lower Coal Measures, with a fringe of Devonian

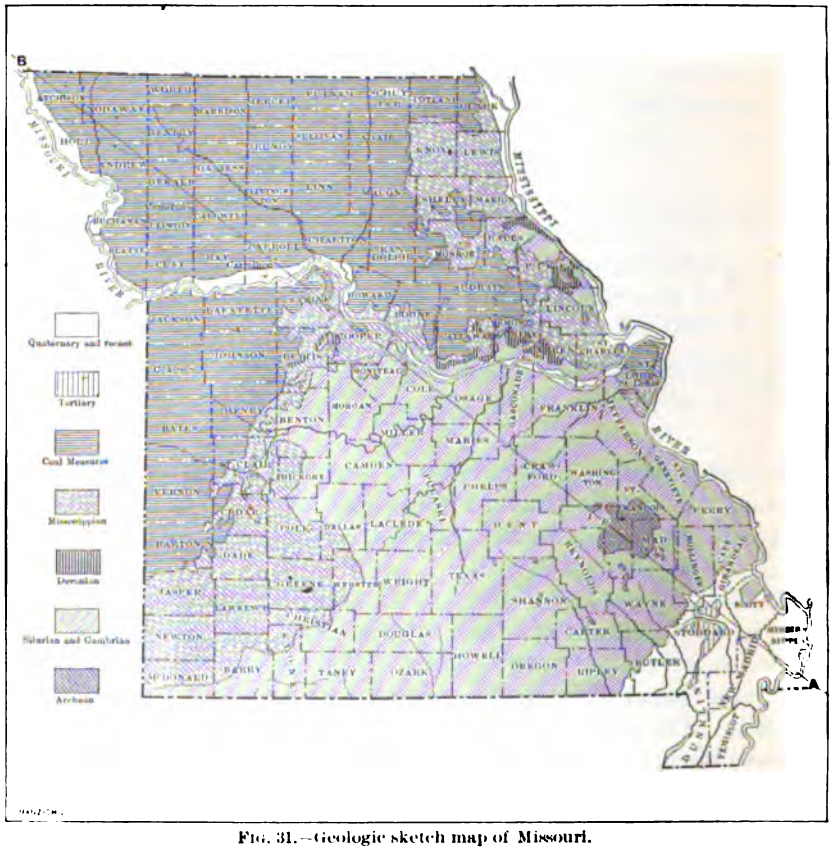

FIG. 31.—Geologic sketch map of Missouri.

and Silurian on the eastern border. The Ozark-St. Francis Dome varies greatly in altitude and in geology. The St. Francis Mountains are made up of Algonkian granite and porphyry. The greater portion of the Ozark region is underlain by Cambrian rocks, composed of alternating beds of dolomites and sandstones. The southeastern lowlands are underlain almost entirely by the sands, clays, and gravels of the Tertiary.

CHARACTER OF THE WATER SUPPLY.

NORTHWESTERN PLATEAU DISTRICT.

The rocks underlying this district belong entirely to the Lower and Upper Coal Measures. The underground water supply of this region is mainly derived from the drift. In the counties bordering the Missouri River, especially Atchison County, small springs are frequent in the bluffs, often occurring one-third of the way to the top. They are also frequent along the valleys of many of the streams. In the greater part of this district drills have shown that the basal stratum of the Coal Measures is a porous sand rock containing occasional beds of bituminous shale, similar to the shale and sandstone forming the basal member (Cherokee shales) of the Coal Measures elsewhere in the State. An abundant supply of water is nearly everywhere obtained from this sandstone by drilling, as is shown by well records furnished by Mr. R. Hawkins, of Chillicothe.

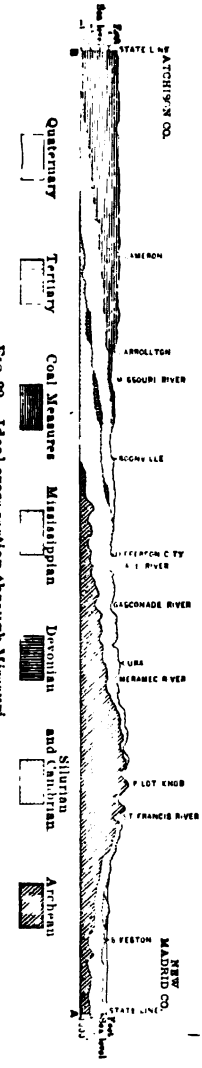

Fig 92.—Ideal cross section through Missouri.

The water from this stratum in widely different localities uniformly carries about 400 grains of salt to the gallon, with some iron, and occasionally sulphur. Mr. Hawkins states that farmers in this area agree that this is very good water for live stock. The pressure is sufficient in Livingston and adjoining counties to cause the water to rise 725 to 740 feet above sea level. Along Grand River bottom the water flows sluggishly out of the wells. As the rocks dip irregularly to the west and north from 10 to 15 feet to the mile the approximate depth of the water stratum may be calculated if the surface elevation is known and allowance is made for the local disturbances producing irregular folds in the strata. The water-bearing stratum varies from 20 to 70 feet in thickness and furnishes an abundant supply of water. Below this water level of the Cherokee shales and sandstones are other water-bearing strata, but, as a rule, they become more highly impregnated with mineral salts as the depth increases, until they are no longer potable.

A few small artesian districts are found in this area. At Tarkio, Atchison County, are seven small flowing wells, varying in depth from 196 to 220 feet. Some of these furnish the city with water. They are evidently derived from higher reservoirs in drift gravel, overlain by an impervious

clay layer. Another flowing well at Bethany, 684 feet deep, furnishes water for the Heilbron Sanitarium. It flows 5 gallons per minute. The source is near the bottom of the well, in the Upper Coal Measures. Another flowing well is reported at Gallatin, Davis County, which probably obtains water from the Upper Coal Measures. There is also a flowing well at G. H. Lawson's, near Utica, Livingston County. The surface elevation here is about 750 feet. The water is saline, and derived from sand rock of the Cherokee shales. The well is 421 feet deep, and drilling was stopped in Mississippian limestone. The water flows sluggishly from the top. There

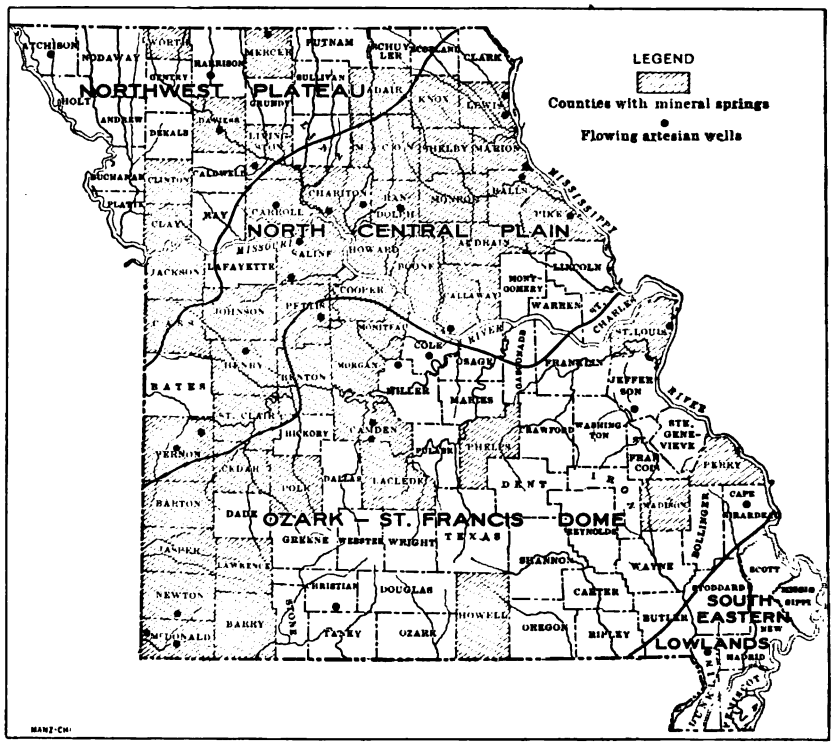

FIG. 33.—Sketch map of Missouri, showing water resources.

are a number of mineral springs and drilled wells supplying mineral waters in this district, some of which have a national reputation. One of the most noted and popular of these is Excelsior Springs, in the northeast corner of Clay County, about 30 miles northeast of Kansas City. In the group of springs at this place the best are the Regent and Siloam springs, both ferromanganese waters, derived from the Coal Measures shales. Two drill wells—the "Sulpho-saline," 1,460 feet deep, and the "Salt-sulphur," 1,370 feet deep—have been sunk in this vicinity, furnishing sulpho-saline waters. No record of these two wells has been preserved, but the writer believes that the waters

are derived from the Jefferson City limestone (Second magnesian, of Swallow). The waters are carbonated and shipped to all parts of the country. Winslow has shown[a] the similarity of the Excelsior Springs waters to those of St. Moritz and Mont d'Or in Switzerland and France.

Cities in this district generally derive their water from adjacent rivers. Wells and cisterns are the most common source of potable water. The former are shallow, from 20 to 50 feet deep, and generally have an abundant supply of water from the drift gravels. Broadhead makes the following statement:[b] "Wherever limestone No. 78 [Bethany limestone] of the Upper Coal Measures prevails we may expect good streams of water just beneath. Springs of any kind are not common in either the Middle or Lower Coal Measures, but are more frequently found where the Upper Coal Measures prevail."

NORTH-CENTRAL PLAIN DISTRICT.

The greater part of this district is underlain by Lower Coal Measures and Mississippian rocks. Fresh-water springs are not very common, especially in the Lower Coal Measures. Salt and mineral springs, some of unusual size, abound. As regards the distribution of underground waters, the district is naturally divided into three sections—the eastern, middle, and southern. The eastern section is largely overlain by drift. Small springs are found at the base of rounded hills of drift and occasionally along outcroppings of the Burlington and Louisiana limestones, and in Warren County good springs are found at the base of the St. Peter (First) sandstone. The main dependence for water in this section, however, is in shallow wells in the drift and in cisterns. In the central section fresh-water springs are rare, and potable water is mainly derived from wells and cisterns, the wells being dug in loess, where that formation occurs. Good water may also be found in the limestones of the Henrietta or the sandstone of the Marais des Cygnes (Pleasanton) shales. This section is noted for the enormous brine springs which are so frequent in Saline and Howard counties. Around some of these brine springs buffaloes in the past have licked away the soil to a remarkable degree. At McAllister Springs is an old buffalo lick, where a valley approximately 25 feet deep, 200 feet long, and 100 feet wide has been excavated. These springs have become popular resorts.

The Big Salt Spring, in Saline County, is a remarkable example of one of these brine springs. The surface rock is near the base of the Mississippian, and the spring proper is an oval pool about 25 feet in diameter. The water boils up all over the surface of this pool, and is impregnated with sulphur. Its source is undoubtedly at a great depth.

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[a] Missouri Geol. Survey, Report on mineral waters, vol. 3, Schweitzer, p. 202.
[b] Missouri Geol. Survey, vol. 1, 1873–4, p. 37.

This spring exhibits a curious fluctuation in temperature. Meek described it in 1855, in his Geological Report on Saline County, as having a temperature of 60°, and as containing an abundance of sulphureted hydrogen. Woodward visited it in 1890 and in his report on The Mineral Springs of Missouri described it as having a temperature of 56°, with little or no sulphureted hydrogen. The present writer visited it in 1903, when he found the temperature to be 64°, with considerable sulphureted hydrogen. Data from these three observations also indicate a steady decrease in the flow of this spring. The temperature obtained by Meek in springs in other localities checks closely with the data obtained by the present writer; therefore the variation is probably not due to difference in thermometers. Meek describes another brine spring adjoining this one as subject to sudden large fluctuations in flow, independent of rains or droughts. He states, "I had the satisfaction to see it in the act of rising. The water was seen to suddenly rise and flow out over perfectly dry ground." This central section seems to be a basin which receives the flow from the Ozarks from the southeast, being apparently inclosed on the south by the Sedalia fold, and probably on the west by smaller folds which have not yet been fully outlined. If this view can be fully verified it might account for the concentration of salines in these waters. The presence of a considerable amount of calcium chloride in all the deep wells and brine springs of this district would presuppose the theory that this was a basin early shut off from the sea, in which the original sea water became concentrated. This section is the most prominent artesian region in the whole State, and will be referred to later. The southwestern section of this North-Central Plain contains a few weak springs, and these are frequently impregnated with alum, sulphur, epsom salts, and sometimes with ferrous sulphate. These are especially noted in Bates, Vernon, and Barton counties. They are mainly derived from the Cherokee shales, which are frequently pyritiferous and magnesian. A number of valuable chalybeate springs are found in this section; they issue from the basal sandstone of the Cherokee shales.

As before stated, this North-Central Plain contains the main artesian areas of the State. In the eastern section of the district an artesian belt extends along the eastern slope of the Winfield-Rensselaer fold. The writer has traced this fold as far north as Rensselaer and believes it to extend still farther north into Lewis County. At Canton, in Lewis County, is an artesian well 906 feet deep, which was sunk in 1890. The first flow of water was struck at 870 feet, in the St. Peter sandstone (First sandstone of Swallow). Sixty feet of this porous sandstone was passed through in the bottom of this well. A gage at the mouth of the well indicates a pressure of 12 pounds. This well supplies the city with water and is leased by Messrs. Griffith and Maggard, who ship large quantities of the water abroad. This is

one of the finest sulpho-saline waters in the State. The well is located on a high bluff overlooking Mississippi River and is surrounded with every adjunct for making a popular health resort. Two other artesian wells were sunk at Lagrange to a depth of 800 and 850 feet. Both obtained their flow from the St. Peter sandstone (First sandstone of Swallow). The water from these is mildly sulpho-saline and is largely shipped to Chicago and other points in Illinois. South of Lagrange, at Hannibal, in Marion County, two other flowing wells were struck at a depth of about 900 feet, the waters being also sulpho-saline, but neither is utilized commercially. Still farther south, at Louisiana, in Pike County, is another sulpho-saline artesian well, strongly impregnated with sulphureted hydrogen. This well is 1,350 feet deep and its flow is very strong. The log of the well has been lost, but it is believed that the main flow comes from the St. Peter sandstone (First sandstone of Swallow).

One of the most interesting wells in the State, and probably one of the oldest drill wells in the United States, is the Spaulding artesian well in the north part of Ralls County, 10 miles west of Hannibal. It was drilled by hand to a depth of 300 feet about 1823, by the Government, in search of brine for the manufacture of salt. The water is very strongly impregnated with salt and sulphureted hydrogen. The flow is very strong and has never perceptibly decreased. The source of the water is undoubtedly St. Peter sandstone (First sandstone of Swallow), as this horizon outcrops in greatly tilted beds a mile to the southeast. A hotel, lake, bath house, and pleasure grounds adjoin the well.

At Bowling Green, in Pike County, the B. B. springs carry 569 grains of mineral matter to the gallon, 475 grains of which are magnesium sulphate. The water is derived from Hannibal shales. Not far distant from these are the Iris and Ionian springs, and the Kalinat well, owned by Mr. I. R. Stevens. The Kalinat water is somewhat similar to the B. B. water in composition, and probably has its source in the Hannibal shales.

This central district has already been referred to as the main artesian region in the State. Wells of this character are located at Huntsville, Randolph County; Salisbury and Brunswick, Chariton County; Carrollton, Carroll County; Sebree, Howard County; Sweet Springs and Malta Bend, Saline County, and Smithton, Pettis County. The Carrollton well is 241 feet deep. The principal flow of saline water was struck at a depth of 200 feet, at the base of the Cherokee shales. The Brunswick well, of sulpho-saline water, is 1,500 feet deep and was sunk at a cost of $1,500. Its probable source is St. Peter sandstone (First sandstone of Swallow). A strong flow of very salt water was struck at 600 feet, probably in the Cherokee shales, but this was shut off by casing. The Salisbury artesian well, also sulpho-saline, was sunk by the city to a depth of 852 feet and at a cost of $2,500.

At Malta Bend, in Saline County, an artesian well was sunk to a depth of 1,250 feet. The first flow, strongly charged with salt and sulphureted hydrogen, was struck at 640 feet, in Cherokee (?) shales. At 840 feet a stronger flow of salt water was struck in sandstone (St. Peter sandstone?). At Sweet Springs a strong flow of sulpho-saline water, estimated at 840 gallons per minute, was struck in a well 1,074 feet deep. The cost of this well, $3,000, was raised by subscription. Excepting a few chalybeate springs, the most notable springs in the central district are the Sweet and McAllister springs. A few years ago the former was a noted resort in the State, with a fine hotel and park. Since the burning of the hotel the property has depreciated, but the mildly saline water is still shipped from the bottling works. The McAllister springs are in a group located about 5 miles from Sweet Springs, the more important of them being the Black Sulphur and two salt springs situated in the old buffalo lick previously described. The conditions for well water are similar to those mentioned in the Lower Coal Measures of the eastern section.

In the western section of the North-Central Plain, on the western flanks of the Ozark dome, are two groups of artesian wells, one at Clinton, in Henry County, the other in Vernon County, at Nevada and Smithton. The writer is indebted to Dr. J. H. Britts, of Clinton, for records of the seven wells, five of them flowing, which were sunk at that place. Well No. 1 was sunk to a depth of 800 feet. At 425 feet a flow of 200 gallons per minute was obtained from the Moreau (Second) sandstone. At 800 feet a flow of 400 gallons was obtained from the Gunter sandstone (Third sandstone). Well No. 7, sunk to a depth of 818 feet, flowed 1,000,000 gallons daily, surpassing all the others combined. It derives its supply from the Gunter sandstone. This well, which yields a slightly alkaline sulphur water, furnishes an abundant supply for the city. Three of these wells are adjacent to one another, and their surplus waters form a beautiful lake, which, with a hotel and park, make a fine pleasure resort.

At Nevada, Vernon County, a well was sunk to a depth of 900 feet, at a cost of $2,500. The principal water was reached at a depth of 550 feet, probably in the St. Peter sandstone. A beautiful park and lake surround this well. Another small artesian well is located at Smithton, in the same county.

The three beds of limestone of the Henrietta formation and some of the sandstone beds of the Cherokee shales are all water bearers and supply good waters.

OZARK-ST. FRANCIS DOME.

This is an area of decided uplift that extends from Missouri River to the Red in Arkansas, and from the Mississippi into Indian Territory. The rocks dip gently in every direction from the elongated

axis. Erosion has cut deep valleys, especially on the eastern side. The two highest points are Taum Sauk, in the St. Francis Mountains, where an elevation of 1,800 feet is reached, and Cedar Gap, in Wright County, 1,700 feet above sea level. Structurally this area is somewhat complex, divergent anticlines merging into the main fold. There is strong evidence of two distinct periods of elevation. In the St. Francis Mountains the granites and porphyries are, it is believed, of Algonkian age. The major portion of the Ozarks are alternating beds of sandstones and dolomites belonging to the Silurian and Cambrian. Bordering these sandstones and dolomites are narrow belts of Devonian and Mississippian rocks. This is preeminently a district of great springs and caverns. In the St. Francis region, however, springs in the crystalline rocks are extremely rare. Considered geologically, the lowest water-bearing horizon, and the most prominent one in the State, is the Gasconade limestone (Third Magnesian). This has a maximum thickness of 500 feet, is frequently cavernous, and some of the largest springs in the country flow from it.

Mammoth Spring, in Arkansas, for example, just over the State line, with its source in Missouri, has a flow of 226,195,200 gallons per day. This is one of the largest springs in the world. Bennett's or Bryce's spring, in Dallas County, has a flow of 161,568,000 gallons per day. Ha Ha Tonka or Gunter's spring, in Camden County, has a flow of 158,982,000 gallons per day. Other immense springs are found in this formation. Greer Spring, in Oregon County, is reported by Prof. H. B. Shaw, of Missouri State University, in his paper on The Water Power of Missouri, published by the university press, to have a flow of 42,000 cubic feet per minute. Meramec Spring, in Phelps County, is reported by the same authority to have a flow of 7,500 cubic feet per minute. Double Spring, in Ozark County, the Waynesville and several other springs in Pulaski County, and a number in Miller, Crawford, and Morgan counties swell this record. As would be expected, great caves and enormous sink-holes abound, the latter marking the course of underground channels. The underground channel of the stream probably forming Mammoth Spring, in Howell County, is outlined by the "Grand Gulf," a wonderful sink three-quarters of a mile long by 200 feet deep. From the bottom of this chasm a cave leads into a more recent channel, exposing the stream, which flows out as Mammoth Spring. The water from this formation is clear, cold, moderately hard, and carries from 10 to 15 grains per gallon—mainly lime and magnesian carbonates.

The Trenton limestone is a prominent water-carrier in Jefferson County. The "Big" or "House's" spring may be mentioned as an example from this horizon.

In the Delthyris shales, of the upper Silurian, springs are particularly abundant and in Perry County are often large.

In the Chouteau group are found weak but highly mineralized springs. Next to the Gasconade limestone, the Burlington limestone is the most important water-bearing horizon in this area. Caves and large springs of remarkable purity, carrying from 15 to 20 grains of carbonates of lime and magnesia to the gallon, are found everywhere in the horizon, notably in Greene, Lawrence, Newton, McDonald, Barry, and Christian counties.

The St. Louis limestone, besides being cavernous, includes some large springs.

While only the more prominent water-bearing strata have been mentioned, it might be said that small but pure cold springs are numerous in all the formations of the Ozarks. A few chalybeate springs, issuing mainly from ferruginous sandstones, are found throughout the district. A few sulpho-chalybeate springs of considerable value issue from the Graydon sandstone of the Mississippian, notably those at Graydon and Eudora Springs, in Polk County, and at Paris Springs, in Lawrence County. Several cities in this district derive their water supply from large springs. Springfield, a city of 32,000 inhabitants, is supplied entirely from the Fulbright Spring, which issues from the Burlington. This remarkably pure spring carries only about 10 grains of mineral matter, mainly calcium carbonate, to the gallon.

A few small artesian wells are found in this district in McDonald, Newton, Christian, Camden, Miller, Cole, Jefferson, and Cape Girardeau counties. In St. Louis County is found a particularly interesting artesian basin, formed by Ordovician and Mississippian rocks dipping strongly underneath a patch of surface Coal Measures in the center.

SOUTHEASTERN LOWLANDS.

In this district the question of pure drinking water has been a serious problem. There are practically no springs. The country is low and frequently swampy, and the surface water contains considerable organic matter. The discovery of artesian water in a well sunk about one year ago at Campbell, Dunklin County, to a depth of 910 feet now points to an easy solution of this difficulty. The first flow of water in this well was reached at a depth of 135 feet, but the principal source was found at the bottom of the well. The water is soft and slightly charged with sulphur.

COMMERCIAL SPRINGS.

Besides being used as resorts or as adjuncts to sanitariums, 18 or more springs place the waters on the market. In 1902 these springs, a list of which is given below, reported shipments of 963,545

gallons, valued at $204,270.[a] The water is used for table and medicinal purposes.

Akesion or Healing Spring, Sweet Springs, Saline County.
American Mineral Springs, St. Louis County.
B. B. Mineral Springs, Bowling Green, Pike County.
Blue Lick Springs, Blue Lick, Saline County.
Browns Lineville Springs, Mercer County, near Lineville, Iowa.
Eldorado Springs, Eldorado Springs, Cedar County.
Excelsior Springs, Excelsior Springs, Clay County.
Haymakers Lineville Springs, Mercer County, near Lineville, Iowa.
Jackson Lithia Spring, Jackson County.
Lineville Mineral Springs, Mercer County, near Lineville, Iowa.
McAllister Springs, McAllister, Saline County.
Magnesia Gusher Spring, Canton, Lewis County.
Monegaw Springs, Monegaw Springs, St. Clair County.
Mysterious Medical Spring, Canton, Lewis County.
Ponce de Leon Well, Desoto, Jefferson County.
Randolph Springs, Randolph Springs, Randolph County.
Sweet Springs, Sweet Springs, Saline County.
Windsor Spring, Windsor, St. Louis County.

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Missouri [well and spring records], by E. M. Shepard: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, pp. 389–440.
Spring system of the Decaturville dome, Camden County, Mo., by E. M. Shepard: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, pp. 113–125.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

IOWA.

By William Harmon Norton.

The underground water resources of Iowa are of two classes. The first includes those bodies of ground water which are fed by the local rainfall and are reached by common wells, or issue as springs wherever the ground-water surface is reached by valleys. Artesian waters, the second class, comprise the more deeply circulating waters which move under pressure through permeable layers of the earth's crust.

SHALLOW SUPPLIES.

On account of the abundant rainfall of the State, there appears to be no considerable area where the waters of the first class are not found within easy drilling distance in quantities sufficient at least for domestic and farm uses. Their distribution, however, is governed by certain geologic conditions which will be briefly sketched.

THE DRIFTLESS AREA.

This area includes a relatively small tract in northeastern Iowa which was never covered by the various ice sheets which spread deposits of drift over the remainder of the State. Its maturely dissected surface has a greater relief than exists elsewhere in Iowa, having a maximum range of 600 feet. The ground water level lies low within the steep-sided and narrow ridges. The limestones which in part form the surface of these uplands are pitted with sinkholes through which the rainfall drains into cavernous passages and rapidly finds way to underlying massive and porous sandstones of great storage capacity, which supply copious springs wherever they are cut by the valleys.

WATERS OF THE DRIFT.

Outside the driftless area the State is covered with sheets of drift of various age. The most recent is the Wisconsin drift sheet, occupying the north-central portion of the State. It presents a surface with countless undrained depressions and streams which have hardly begun the work of erosion. Ground water here stands high, and exuding in the sags gives rise to the many lakelets and the extensive sloughs of the region.

The Iowan drift sheet, which forms the surface in the northeastern portion of the State, has a topography that is somewhat older than

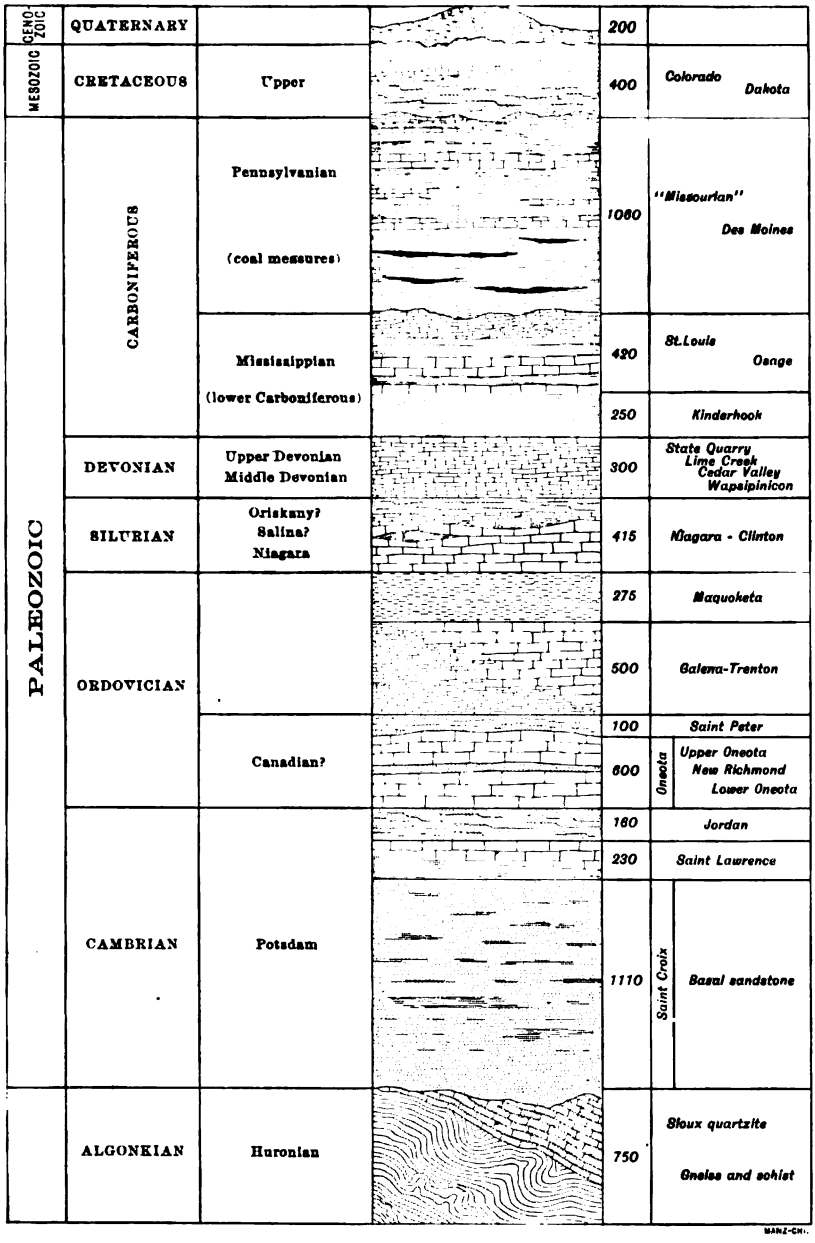


Fig. 34.—General geologic section of Iowa.

that of the Wisconsin, the lakelets and sloughs having been largely drained by the natural erosion of the streams.

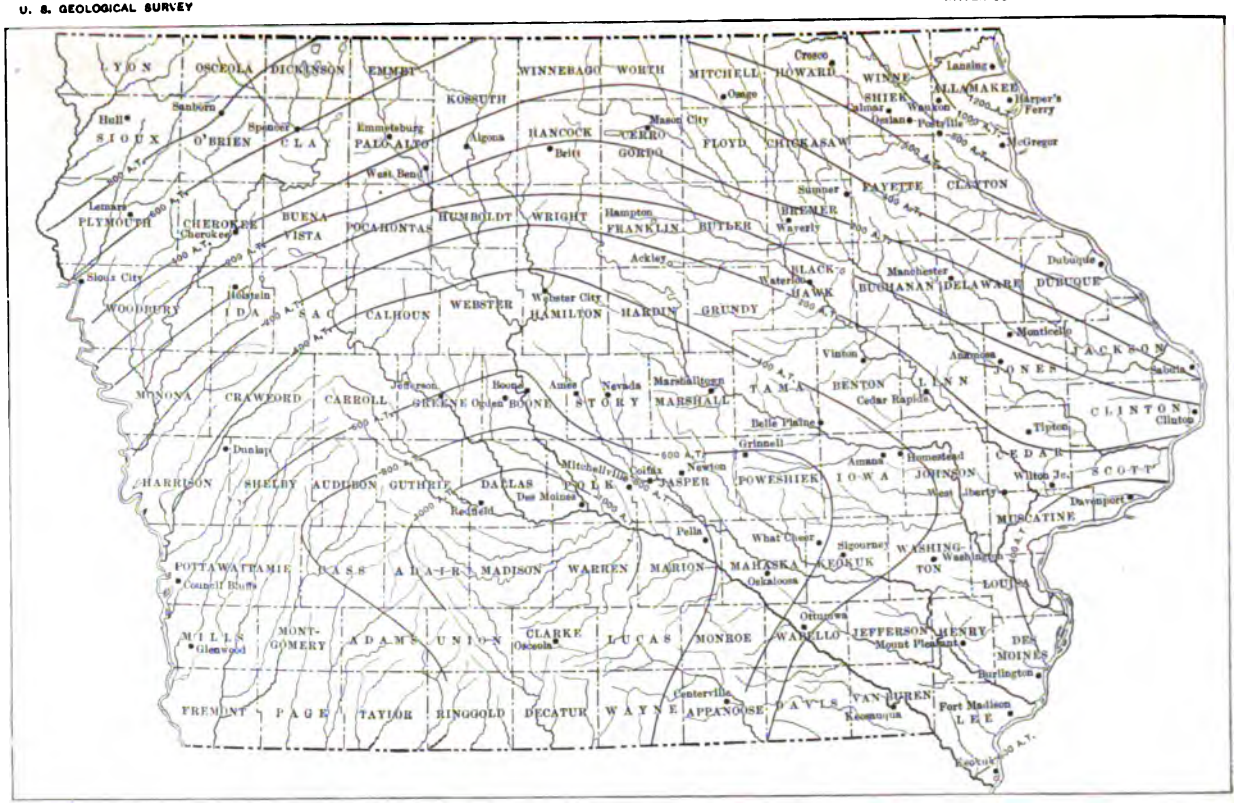
Except a narrow strip along Mississippi River, extending from Scott County southward, which was invaded from the east by the Illinoian ice, the remainder of the State is covered with the Kansan drift sheet, an old drift deeply weathered, and for the most part much cut by streams before the deposition of the surface silt known as "loess." Beneath the Kansan Iowa geologists have recognized still earlier drift, without surface outcrop, known as the "pre-Kansan."

Overlapping one another like the shingles on a roof, these broad sheets of stony clay, with their attendant beds of sand and gravel, largely control the distribution and the quality of the ground water of common wells. The stiff, stony clays of which the drift is chiefly composed are impervious and dry, water being found only in the seams of sand and gravel included within the mass of the drift sheet, and especially in the broad gravel and sand layers by which the successive sheets of drift are often separated, or which often immediately overlie the country rock. Thus the Buchanan gravel, a weathered and thoroughly oxidized deposit of Kansan age, is an important source of supply, even where lying beneath the stony clays of more recent ice invasions.

The drift is so thick and the distance to the various water-bearing layers so great that wells must frequently be sunk to depths of 100 feet or more. Except on special areas such as river plains, where ground water stands near the surface, the windmill is a marked feature of the typical Iowa landscape.

ARTESIAN WATERS.

The artesian field of Iowa is part of the extensive artesian area of the upper Mississippi Valley, which includes also a portion of Missouri, a large part of Illinois, and southern Minnesota and Wisconsin. The catchment area of the field lies for the most part in the two States last mentioned. From this gathering ground a succession of beds which supply all the requisite conditions for artesian wells slope southward. The series consists of many broad sheets of limestones, sometimes cavernous, of impervious shales, and of close-textured to porous sandstones, whose total thickness, as found by adding together the maximum thicknesses of the different formations, amounts to 6,000 feet. These strata, which include representatives of nearly all the stages of the Paleozoic system, and in western Iowa of some of the Mesozoic, rest on a floor of quartzites and schists of Algonkian age. In northern Iowa the strata also dip from the eastern and western boundaries of the State toward a median line, forming a shallow trough or syncline, whose axis lies in about the longitude of the upper Des Moines River. In southern Iowa the western limb of this syncline is depressed, and under the southwestern counties the rock sheets lie more nearly



ARTESIAN LOCALITIES IN IOWA.

The lines show the elevation of the summit of the St. Peter sandstone above sea level.

level. In southeastern Iowa the lower beds rise in a low dome now covered and concealed beneath later formations.

So exceedingly gentle are the dips of these strata that the catchment area is of great width, and the supply of the artesian reservoir correspondingly ample. Of perhaps still more importance is the consequence that even the basal water-bearing beds are within drilling distance over about four-fifths of the State. So far as known, their continuity is not interrupted by any fault or break barring the way of their percolating waters or presenting lines of leakage.

Cambrian rocks.—The lower division of the Cambrian may be called the St. Croix or basal sandstone. It rests directly on the Algonkian floor. It is at least 1,100 feet thick in the vicinity of the Mississippi River, but thins rapidly as it rises on the western side of the central syncline. All its pervious strata are water bearing, except where its summit lies above the ground-water surface along the Wisconsin border. Beyond the counties bordering the Mississippi in northeastern Iowa the nearly static waters of this deep reservoir are likely to be heavily mineralized. Thus at Cedar Rapids in a well that reached the Algonkian quartzite at 1,417 feet below sea level, the basal sandstone waters were so salty and so corrosive to the iron casing that the boring was plugged to shut off all water below that of the Jordan.

The most important water-bearing bed of the Iowa field is the Jordan sandstone, a light-colored, smooth-grained rock, from 100 to 200 feet thick. It is to this water-bearing stratum that drillers are usually encouraged to go, and it is here that they are often also urged to stop. The Jordan is separated by impervious shales and shaly dolomites, called the St. Lawrence, from the basal sandstone.

Ordovician, Silurian, and Devonian rocks.—At the base of the Ordovician is the Oneota (Lower Magnesian), a dolomitic formation, which may be divided into an upper and a lower division, separated by a bed of sandstone equivalent to the New Richmond of Wisconsin. With a thickness of from 300 to 600 feet, it appears to underlie the entire State, everywhere showing the perfect and complete dolomitization and admixture with arenaceous material characteristic of its outcrop. The flow of an artesian well is often notably increased as the drill penetrates this creviced and porous formation with its included sandy layers.

The St. Peter is a remarkably persistent formation whose normal thickness is about 100 feet. It is a bed of incoherent quartz sand, which, because of its freedom from clays and cementing material and because of the phenomenal roundness of its grains, is an exceptionally important water horizon. So distinct are its grains from those of any sandstone above it that the St. Peter is easily recognized by the experienced well driller as well as by the geologist. In northern Iowa,

even as far west as Cherokee, it yields fair supplies of water derived from its outcrops in Minnesota.

Above the St. Peter is the Galena-Trenton, a body of limestone underlying considerable areas within the State. The Galena-Trenton is shaly at its base, and in places thoroughly dolomitized. The dolomitic phase, being porous and often creviced, occasionally yields artesian water, as at Davenport, the water apparently being derived from the underlying sandstone.

The Ordovician series includes as its highest member the Maquoketa shale, which has a maximum thickness of 275 feet, and which, in eastern Iowa at least, effectively seals the formations beneath it. Where it lies near the surface and the Silurian (Niagara) limestone forms the country rock, it gives a water-tight floor, immediately above which water may often be obtained by ordinary wells in quantities sufficient for village supplies.

The Devonian and Silurian rocks are of slight importance except in southeastern Iowa, where the latter become arenaceous and yield a bountiful supply at Keokuk and Fort Madison.

Carboniferous rocks.—The importance of the Carboniferous system as a source of water supply is in part due to its wide extent west of Iowa River. Despite its great thickness—the lower or Mississippian division measuring 670 feet and the upper or Pennsylvanian division (Coal Measures) reaching a thickness of 1,060 feet—the permeable strata of the series are neither thick nor persistent. A number of flowing wells are, however, supplied from it, although their waters are often heavily mineralized and their discharge slight. The well-known medicinal wells of Colfax furnish a typical example. In wells which reach the deep-lying beds beneath the Carboniferous, these upper waters, often impregnated with the sulphates of lime, soda, and magnesia, are not always effectively cased off.

Dakota sandstone.—The Dakota sandstone, which is a source of some importance in northwestern Iowa, is cut off from the great Dakota field, where it carries an enormous volume of water under high head, by the mass of Sioux quartzite of southeastern South Dakota. In Iowa its water is under little head, and so far as tested is of poor quality.

Summary.—Successful artesian wells have been drilled in all parts of the State except on the high divides in southwestern Iowa, where the water-bearing rocks reach their greatest depth below the surface. More than 150 artesian wells—not counting those in glacial drift, which are numbered high in the hundreds—have already been drilled at an expenditure estimated at not less than $500,000. The water supply of some of the larger cities of the State—such as Dubuque, Cedar Rapids, Clinton, and Boone—is drawn in considerable part from artesian wells, but is supplemented from other sources. In

the cities the larger number of artesian wells are of private ownership, having been sunk by various manufacturing companies, such as packing establishments, breweries and bottling works, glucose works, and ice factories. In the number of artesian wells, Davenport heads the list with 14 or more. For smaller towns artesian water forms an ideal supply, and about 30 of such towns within the State have already availed themselves of it. Pure, unpolluted artesian waters are provided for a number of the State institutions, including the State College of Agriculture and Mechanic Arts, the two penitentiaries, two hospitals for the insane, and three of the minor institutions.

MINERAL SPRINGS.

Six of the springs of Iowa reported sales of their water for table or medicinal uses in 1902. They are as follows:

Boone Mineral Well, Boone, Boone County.
Colfax Mineral Spring, Colfax, Jasper County.
Fry's Colfax Mineral Springs, Colfax, Jasper County.
Lake View Medical Spring, Lake View, Sac County.
Ottumwa Mineral Springs, East Ottumwa, Wapello County.
White Sulphur Spring, near Davenport, Scott County.

The sales reached an aggregate of 152,050 gallons valued at $14,655.[a]

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 161–163.
Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 39–41.
Artesian wells of Iowa, by W. H. Norton: Iowa Geol. Survey, vol. 6, 1897.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

MINNESOTA.

By C. W. Hall.

TOPOGRAPHY.

The topographic features of Minnesota are simple, and its relief is low. The highest point of the State—the Misquah Hills in the northeastern corner—is only 2,230 feet in altitude. The lowest point is the shore of Lake Superior at 602 feet. The average elevation is very close to 1,200 feet, since there are 42,390 square miles below and 41,897 square miles above the 1,200-foot level.

WATER RESOURCES.

GENERAL CONDITIONS.

The northeastern portion of the State seems so thoroughly well watered by streams, lakes, and springs that thus far there has been no strong demand for artesian water, and indeed the crystalline rocks lying immediately beneath the glacial drift offer an effectual bar to artesian boring. In the central portion of the State there is an occasional basin in which artesian waters gather and in which there are wells of moderate depth. In these parts of the State much of the surface is too high to obtain flowing water, and is so high that only occasionally can supplies be obtained by pumping. Thus the southeastern and northwestern portions of the State are the only areas which may be regarded as artesian basins in any broad sense of that term.

Exploration for water in Minnesota during the last twenty-five years has shown that artesian waters are derived from a wide range of geological formations, which are grouped according to geologic age into Eo-Paleozoic, Cretaceous, and Glacial drift. There are few areas within the State where waters are not obtainable from at least one of these three groups, if they be obtained at all.

WATER-BEARING STRATA.

There are no water-bearing strata below the Paleozoic. Within the Cambrian and Ordovician rocks, which stretch in a widening belt from Duluth southward to the Iowa line, is a succession of sandstones alternating with shales, dolomites, and dolomitic limestones that yield copi-

ous supplies of artesian waters. Comparatively little exploration has been done within this area from Duluth southward to Hinckley, the rocks being too thin and too high above the sea; but from Hinckley to the Iowa line scores of wells have been sunk, which, with very few exceptions, yield a supply of water.

Cambrian.—This series of dolomites, shales, and sandstones varies considerably, as shown by many exposures in the upper Mississippi region. In the St. Croix region is a series to which Dr. C. P. Berkey has given the name Basal sandstone.[a] At the base of this series is a persistent sandstone, attaining a thickness of 1,000 feet at Minneapolis and gradually thinning out in all directions as though beneath this point was the deepest part of a great basin of deposition. So frequently has this bottommost sandstone layer been reached in artesian well boring, that its characters and those of the overlying rocks are thought to be pretty definitely established.

Above this sandstone is a bed of shales and dolomites of varying thickness and texture, which is called locally the St. Lawrence formation. Upon it rests another sandstone series called the Jordan, which locally attains a thickness of 116 feet. This is remarkably porous and is strongly water bearing, yet it is made up of unusually well-rounded and symmetrical grains, varying in coarseness from one-sixteenth of an inch down to granules of extreme fineness.

Ordovician.—Resting upon the Jordan sandstone is the Oneota formation, the most massive and uniform as well as the thickest bed of dolomite within the State. While the Oneota formation in many places is very porous through its dolomitization, it nowhere carries water sufficient to serve as a source of water supply.

Above the Oneota is a layer of sandstone called the New Richmond sandstone. Although this is a very thin layer, nowhere exceeding 20 feet in thickness and in places completely lost sight of by well borers, yet in a few localities it has become the source of a generous water supply. Upon this New Richmond sandstone, which appears to be the basal conglomerate of the Canadian series of the upper Mississippi Valley, rests a dolomite of somewhat unique characters, which for Minnesota has been named the Shakopee. This is of varying thickness and everywhere thoroughly dolomitized. It represents a formation much altered from its original condition. That it once was much thicker than at the present time there is every reason to believe. It sometimes carries small lenticular beds of sandstone, which in certain portions of the State appear as quite conspicuous features in the formation. Elsewhere their absence is a marked characteristic.

Resting upon the Shakopee with some unconformity, evidenced in part by the varying thickness of the Shakopee beneath, is a persistent sandstone called the St. Peter. This sandstone at Minneapolis and

[a] Berkey, C. P., Geology of the St. Croix Dalles; Am. Geol., vol. 20, 1897, p. 372.

St. Paul is over 160 feet in thickness. Southward it thins to 75 or 80 feet, while at other points it becomes thicker. According to measurements in river valleys and artesian well borings its thickness is variable. This is an unusually strong water-bearing formation, and is utilized wherever it occurs as a source of water. To the north of Minneapolis, where the overlying rocks are removed and the St. Peter itself thinned by erosion, it yields water at varying depths, pumped by windmills for the use of the farm and the truck garden. The last of the Ordovician series in this part of the State is the Trenton-Galena limestone. This has been so eroded by glacial wear that in places it is not more than 10 or 15 feet in thickness, but elsewhere, where protected from erosion, it attains a thickness of 200 or 300 feet. This rock contains no water, but when present serves as an effective cap in confining the waters of the underlying formations.

Cretaceous.—Less is known of the Cretaceous than of any series represented in the State. According to the records of wells, Cretaceous rocks come in from the Dakotas, where well-defined Cretaceous beds occur, and stretch over the divide of crystalline rocks and, in probably continuous beds of sandstones and shales, reach more than half across the State. Yet many portions of Minnesota, even in its western half, show no evidence of the existence of Cretaceous rocks between the glacial drift and the underlying pre-Cambrian rocks. The thickness of the Cretaceous varies and its altitude above the sea is far from uniform. The freedom with which water is obtained from this formation is a valuable factor.

Glacial drift.—This deposit is a remarkably persistent covering for all the older formations. In southeastern Minnesota for a few thousand square miles it is absent. Here the pre-Paleozoic rocks stand out at the surface as the prominent bed rock of the region. This area, named the driftless area by Chamberlin and Salisbury, is a part of the physiographic region embracing southwestern Wisconsin, northwestern Illinois, and northeastern Iowa. The glacial drift nearly everywhere carries water, the places where a sufficient supply can not be found being very few indeed. In thickness the deposits vary from 0 to 300 feet. Mr. Upham thinks that in the western half of the State they can not average more than 75 feet and in the eastern half they are 50 feet thick outside the so-called "driftless area" of the southeastern corner. The glacial drift affords waters through three distinct methods—artesian wells, shallow wells, and springs.

ARTESIAN BASINS.

The artesian basins of Minnesota may be briefly described as the (1) Southeastern artesian basin, (2) Red River Valley basin, and (3) small local basins.

Southeastern artesian basin.—This basin is within the area of the

pre-Paleozoic rocks. Each one of the several sandstones in the series will yield water wherever it is present under the necessary conditions. The pre-Paleozoic rocks are in the form of a great arch or dome, the crest of which seems to lie in Rice, Goodhue, and Dakota counties. From this dome the Trenton limestone is worn away and the St. Peter sandstone has been subjected to erosion almost sufficient to sever its southern from its northern area. The lowermost of the sandstone

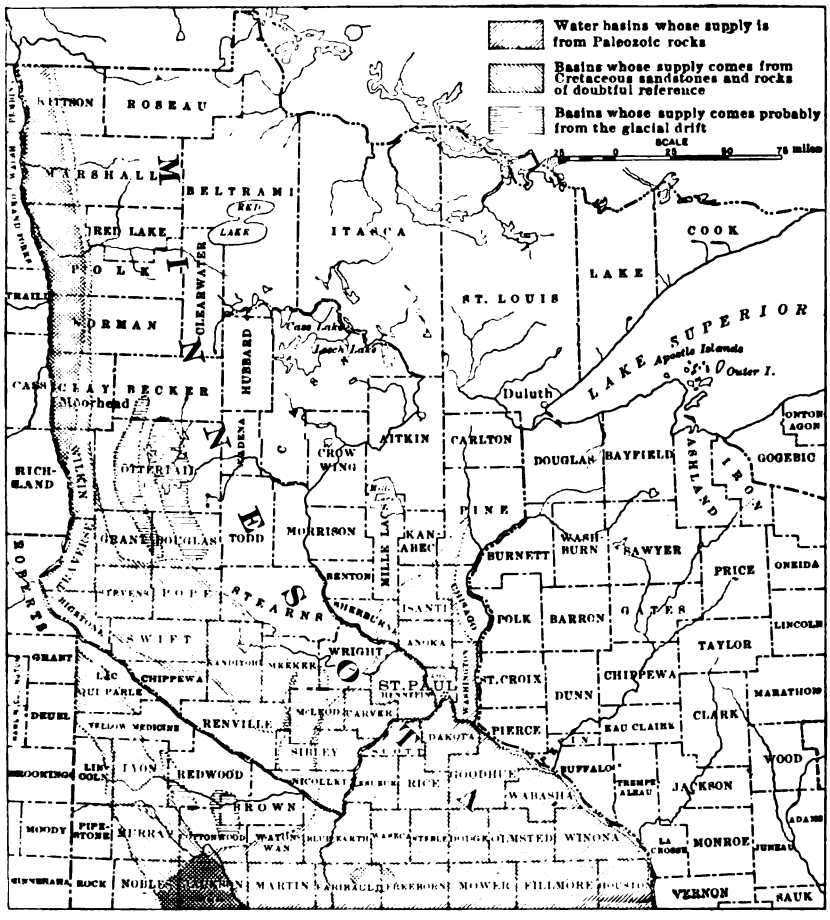


FIG 35.—Artesian basins of Minnesota.

series in this region seems to have a great thickening beneath Minneapolis and St. Paul. A well sunk in Lakewood Cemetery, Minneapolis (elevation 975 feet), disclosed granitic rocks 2,150 feet below the surface. Along the southern border of the State at Winona, Brownsville, and also La Crosse, Wis., granitic rocks were struck at about 525 feet below the level of the Mississippi, where the surface altitude was 625 feet. Since granitic rocks occur at St. Cloud at 1,200

feet above sea level the basin-shaped nature of the bottom of this water-bearing district is clearly seen.

The Southeastern artesian basin lies within the portion of the State first settled. The population within this region is comparatively dense, being, it is estimated, about 100 per square mile. Several towns and many farmers get their principal water supply from artesian sources. It is estimated that 250 wells are now furnishing water within this area.

Red River Valley basin.—In Red River Valley all three of the great water-bearing series are drawn upon for artesian supplies. Comparatively few wells have been sunk to the Paleozoic rocks of northwestern Minnesota, but these few show that the Cambrian and Ordovician are water bearing. With exactly what formation in southeastern Minnesota Red River Valley sandstones can be correlated is impossible to determine with the data now available. The water is of fair quality, abundant quantity, and apparently permanent supply. The Humboldt well, the deep well at Moorhead, and a few others show the nature of the rocks and the quality of the water.

The second water-bearing beds are the Cretaceous sandstones. These are much more strongly developed in the southern end of the district than toward the north, and they show a very apparent tendency to thin out in passing eastward from the Red River and the Bois des Sioux River, which form the boundary between the Dakotas and Minnesota, toward the eastern border of the Red River basin. Indeed it is thought by some that the Dakota sandstone, the the remarkable water-bearing stratum of the James River basin, thins out and disappears before the Red River Valley is reached. Whatever the case, the sandstones which yield the water are uneven in texture, and of varying thickness and mineral composition. The number of wells within Red River basin in Minnesota drawing water from the Cretaceous sandstones is large. Mr. Warren Upham estimates[a] that hundreds exist. Nearly every large farm in the valley has a deep, or artesian, well to supply farm buildings, gardens, and pastures. The surface water and the shallow well water are in many places so alkaline and so disagreeable to the taste that they can not be used successfully.

The third source of artesian waters is in the deeper layers of the glacial drift. Within the great plain of Red River Valley wells in the drift vary from 50 to 150 feet in depth, but in the moranic regions to the east of Lake Agassiz Plain a greater depth is frequently attained. The water from these wells is wholesome and is very generally utilized.

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[a] The Glacial Lake Agassiz: Mon. U. S. Geol. Survey, vol. 25, 1895, p. 523.

SHALLOW WELLS.

By shallow wells is meant those wells from 10 to 100 feet in depth, sunk chiefly for domestic water supply. They are in general use among the farmers, and in the newer towns and villages there are large numbers of them. In older communities they are gradually being displaced by deep borings or, where conditions are favorable, by a supply from lakes or streams of recognized purity. Save in southeastern Minnesota these wells are almost invariably within the glacial drift. The water level in the drift follows so closely the general contour of the surface that there are few wells which do not yield a sufficient supply of wholesome water within shallow depths.

In the southeastern corner, within the so-called driftless area, shallow wells reach into the residual material derived from the alteration of the Paleozoic formations which occur in this portion of the State. The waters here are hard, but as a rule clear and wholesome. The water level is steadily sinking, so that farmers and others utilizing this supply are obliged to bore their wells deeper than formerly. Old wells must be deepened, and even then their supply is less than in former years. It is the general impression that the large demands for water from underground supplies exceed the inflow from the surrounding catchment areas, and thereby the diminution in quantity becomes a question of serious concern.

SPRINGS.

While springs occur throughout the State, there are certain structural conditions which locally prevent their formation. These are the stretches of modified drift and the glacial lake bottoms extended between the morainic belts characteristic of the topography of the State. There are not less than twelve of these moraines in the State. These belts of gravelly ridges and mounds are the source of supply of wholesome yet, in most areas, hard spring water.

There is no especial mode of occurrence noticeable in the distribution of springs. Their place of appearance depends upon the arrangement of the drift material through which or under which the water makes its way, beds of clay of greater or less extent being usually the determining factor. In the northeast portion of the State the conditions of occurrence are quite simple, since the waters gathered in the shallow glacial drift make their way out through the hollows worn by glaciation. In southeastern Minnesota springs occur along the river valleys and represent the completion of the underground circulation through the pre-Paleozoic rocks. The conditions of occurrence are determined by the depth of the river valley and the composition and texture of the rocks through which or between which the waters flow.

The spring water of northeastern Minnesota seems to be softer than any other water in the State. Waters in southeastern Minnesota are, with scarcely an exception, hard. In the western part of the State the underground circulation is comparatively sluggish throughout the extent of the level tracts of glacial drift, which here carries a large proportion of fragments from calcareous shales and Mesozoic limestones. There are many alkaline springs as well as alkaline wells, and hardness is a universal characteristic of the water in this part of the State.

The following springs reported sales of water in 1902:[a]

Highland Spring, St. Paul, Ramsey County.
Indian Medical Spring, Elk River, Sherburne County.
Inglewood and Glenwood Springs, Minneapolis, Hennepin County.
Mankato Mineral Springs, near Mankato, Blue Earth Connty.
Trio Siloam Springs, Austin, Mower County.

The number of gallons sold is given as 2,217,000. The value was $415,140.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 158–159.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 55–57.

Minnesota [well records], by C. W. Hall and J. E. Todd: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, pp. 441–488.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

WISCONSIN DISTRICT.

By Alfred R. Schultz.

LOCATION AND TOPOGRAPHY.

Area included.—The Wisconsin district lies between Lake Superior and Lake Michigan, extending southward approximately to the parallel 41° 30′, and comprising all of the State of Wisconsin, the Northern Peninsula of Michigan, and that portion of Illinois north of the Carboniferous deposits.

Topography.—In general the area is a broad plain, dipping toward the south. Portions of the area are rugged and rocky and broken by hills, which in the western part of Michigan rise to a height of 2,000 feet. North of a central elevation, which ranges between 1,500 and 2,000 feet, the remnants of a mass uplifted in early geologic times, there is an abrupt declivity which reaches to within a few miles

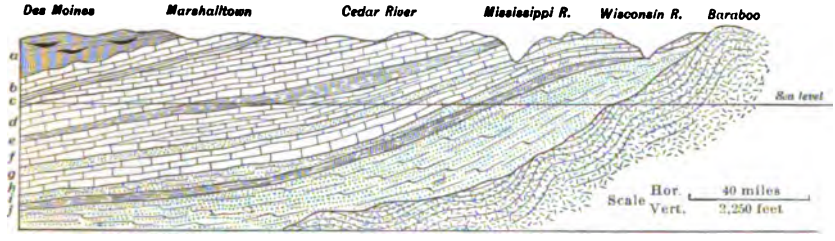


Fig. 36.—Geologic section from Baraboo, Wis., to Des Moines, Iowa. After Norton.
a, Des Moines; *b*, Mississippian; *c*, Kinderhook; *d*, Devonian-Silurian; *e*, Hudson beds; *f*, Galena-Trenton; *g*, St. Peter; *h*, Oneota; *i–j*, St. Croix, including Jordan, St. Lawrence, and Basal sandstone.

of the shore of Lake Superior, 622 feet above sea level. Across the entire northern portion of the area the divide is generally close to Lake Superior. It is lowest in the eastern half, where the Paleozoic rocks form the crest. South of the central elevation is a long slope, which in the southern part of the area is approximately 500 feet above sea level.

The central upheaval, together with two minor transverse swells, determined the chief drainage systems of the area and in a general way govern the circulation of the underground waters.

Among the minor topographic features are the elevations due to the Baraboo and Wausau quartzites, the Penokee-Gogebic and Marquette

iron ranges in Michigan, and the sawtooth ridges of Keweenawan rock in the northwestern part of the district, all of which have affected the drainage and underground circulation. Extending from Green Bay, Wis., diagonally across the area to Rock Island, Ill., is a valley excavated in the soft, easily eroded Cincinnati shale. Its eastern boundary is a steep slope, composed of the resistant Niagara limestone. This valley is one of the most important of the district, many flowing wells being found within its borders. North of Green Bay the rivers, for the most part, cut directly across the underlying shale, but well borings show that the drift here is much deeper than over the Niagara limestone to the east, indicating the continuation of the ancient valley.

GEOLOGY.

Pre-Cambrian rocks.—The elevated central region of Wisconsin consists of pre-Cambrian granites, syenites, and schists, all having a very low crystalline texture and porosity.

North of the crystalline area are the Huronian deposits which form the Penokee-Gogebic iron range with its steep dip to the north, while on the northeast is the trough of the Marquette iron range. Rocks of the same age lie on the east, southeast, and on the southwest of the pre-Cambrian elevation, while small isolated outliers are found scattered over south-central Wisconsin.

The Keweenawan series, which overlies the Huronian, is confined to the northwestern portion of the area lying north of the Huronian of the Penokee-Gogebic iron range. The Keweenawan series extends from the most northern point of Keweenawan Point in a southwesterly direction across the district to St. Croix Falls, where it passes into Minnesota. The rocks lie in a synclinal trough whose axis bears northeast and southwest. In the northern half of the formation only the eastern portion of the trough remains, while the western portion probably lies beneath the surface of Lake Superior. The rocks consist of basic and acidic lavas, conglomerates, and sandstones, three-fourths of which are igneous. The closing of the Keweenawan age also marks the end of volcanic activity within the area.

Potsdam sandstone.—Nearly surrounding these pre-Cambrian rocks, which carry very little water, is the Potsdam sandstone, which rests unconformably and horizontally upon the former. North of the crystalline rocks is a belt of sandstone of varying width bordering Lake Superior.

On the south the same formation extends in a crescent around the crystalline area, with its northeast prong joining the Lake Superior belt near Marquette, Mich., and its northwestern prong passing into Minnesota near St. Croix Falls, Wis.

The sandstone adjacent to Lake Superior in the western half of the

area is of a red and brown color, well cemented and firm. Eastward the color becomes lighter and the eastern portion as well as that on the south is white or yellow, poorly cemented and unconsolidated, often crumbling in the hand, while in some cases it is so hard that it might pass for a quartzite. The formation consists of fine calcareous sand, coarse siliceous sand, shales, marls, and layers of sand highly impregnated with iron oxide, thereby causing the water from some of the

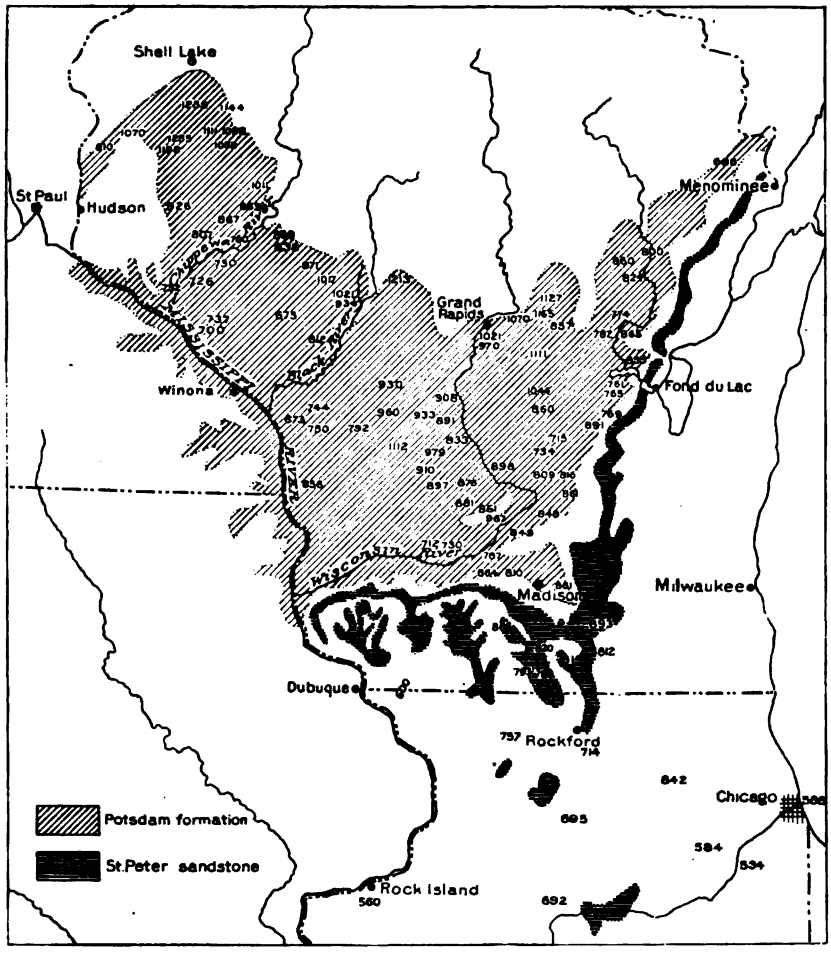


FIG. 37.—Wisconsin outcrop of Potsdam and St. Peter sandstones.

horizons to flow forth a blood red. The rock is very porous. Its grains are angular, and in some of the lower layers as coarse as No. 4 shot. The sandstone underlies the entire area to the east and south, dipping east, south, and west on the sides of the central elevation. Its thickness varies from nothing along the crystalline margin to 1,488 feet at Rockford, Ill. At Streator, Ill., it has a total thickness of more than 1,737 feet, showing a rapid increase toward the south.

Lower Magnesian limestone.—Fringing the Potsdam sandstone on the south from the eastern part of Michigan to St. Croix River, in Polk County, Wis., is a narrow belt of Lower Magnesian limestone, varying in thickness from 50 to 200 feet. Along St. Croix and Mississippi rivers it caps many of the sandstone ridges. It is a dolomite, with considerable quantities of chert, crystalline quartz, and quartzose sand scattered through it near the middle of the formation.

St. Peter sandstone.—The St. Peter sandstone, which overlies the Lower Magnesian limestone, consists of a soft incoherent rock, of large well-rounded grains of quartz varying in color from white through yellow, pink, to a deep red. The formation is mapped in Michigan with the Lower Magnesian limestone and follows the eastern margin of that formation southward to the Illinois boundary, thence up the Mississippi to Vernon County, where it is all eroded. It reappears in Pierce and St. Croix counties. Isolated portions are also found farther south in Illinois, where erosion once more has brought it to the surface. The northern half of the eastern margin is considerably thinner, often being pinched out entirely, as shown by well records. The formation has a thickness varying from 0 to 250 feet in portions of Illinois.

Galena-Trenton limestone.—The Galena-Trenton limestone occupies a large surficial area extending from eastern Michigan southwest across the country to the Mississippi River, in Crawford County, Wis., and as far south as the southern boundary of the district. Small isolated patches are found capping the highest hills in Pierce and St. Croix counties in west-central Wisconsin.

The upper portion is a dolomite while the lower is more of a limestone. The various beds of this formation are often separated by shale. The rock contains many cracks and fissures which are partly filled with calcite, pyrite, marcasite, galena, and sphalerite. The combined thickness of the Galena-Trenton varies from 200 to 350 feet.

Cincinnati shale.—Overlying the Galena limestone is a formation composed largely of bluish to greenish shale with occasional thin bands of limestone. This shallow sea deposit is known as the Cincinnati shale and is one of the most impervious strata of the area. These soft shales are easily eroded and seldom exposed. They outcrop in a narrow belt seldom more than a few miles in width and close under the protecting Niagara limestone, extending from eastern Michigan southwestward to Rock Island, Ill., forming for the most part the Green Bay and Rock River basins. Another prong extends southeast from Lee County, Ill., around the Carboniferous deposits to the southern boundary of Ford County. A small area is found also in northwestern Illinois, along the Mississippi River. The thickness of the formation may be placed between 150 and 450 feet.

Niagara limestone.—East of the Cincinnati shale occurs the Niagara

limestone, which, in a few places, is separated from the shale by the Clinton iron-ore deposits. The Niagara deposit varies in thickness from 450 to 800 feet and extends from the eastern point of Michigan around the lake on its western shore, passing into Indiana southeast of Chicago. A small area is also found along the Mississippi River north of Rock River, capping many of the mounds in southwestern Wisconsin. The formation has a large surficial extent in the eastern part of the area. It is composed largely of calcium and magnesium carbonates and contains a large number of flints. Some portions are hard and cherty, while others are inclined to be sandy.

Later rocks.—Later deposits of rock within the area are of minor importance and occur over very small areas. In Milwaukee and Ozaukee counties in Wisconsin occur small deposits of the Lower Helderberg limestone, while in Milwaukee and St. Ignace, Mich., and south of Rock Island, Ill., occur remnants of a more extensive Devonian deposit.

Drift.—The entire area was overridden by glaciers, except a small part along Mississippi River, extending from Alma, Wis., eastward to Grand Rapids, thence southward until it crosses the Mississippi again near Savanna, Ill., passing into Iowa. The ice sheet left a heterogeneous deposit of clay, sand, bowlders, etc., of varying thickness, burying and modifying the minor topographic features, and governing to a large extent the drainage and the occurrence of surface water throughout the greater portion of the area.

Lacustrine deposits.—Along the borders of Lakes Michigan and Superior are lacustrine deposits composed of alternating layers of red clay and beach sand. These deposits offer one of the cheapest and most satisfactory means of obtaining water for both farm and city purposes.

WATER SUPPLIES.

From the foregoing brief description of the topography, drainage, and geology of the district it may readily be understood that the source of water supply for the crystalline region, with the exception of some of the sandstone of the Keweenawan epoch and the softer horizons of the Huronian, is restricted chiefly to the overlying bed of drift. This area as a whole has a very poorly developed drainage. The water table in most cases lies near the surface. Deep wells are seldom needed in this sparsely settled region. Cool, soft, and comparatively pure water may easily be obtained from the numerous springs, small streams, ponds, rivers, and lakes. Considerable difficulty, however, has been experienced in various places where a large quantity of water was required some distance from a lake or river; in such places the water-supply problem will take on a more and more serious aspect as the country becomes more thickly settled.

Potsdam sandstone.—The greatest of the rock water horizons of the

area, and the one that universally furnishes a large supply of water, is the Potsdam sandstone, which nearly surrounds the crystalline rocks. To the south and east this formation is the great source of the artesian waters found scattered over the district. On the north a few records show that waters from its beds rise considerably above the level of Lake Superior. The impervious interbedded shales of this formation furnish ideal conditions for a good artesian supply at many places within the outcrop area itself. The shales, though not everywhere present, often give rise to several separate horizons of water-bearing rock. Wells of this nature may be found at Sparta, Whitehall, Durand, and numerous other places in Wisconsin. Although the water from this formation does not reach the surface in many places, owing to the topography, it is always abundant, and may be depended upon as a supply for city purposes. On account of the advanced erosion and deep-cut valleys the entire Potsdam area west of Green Bay and north of Wisconsin River does not obtain any artesian water from beyond its own limits. Although water is abundant everywhere the artesian flows of this area are confined to the Mississippi Valley and its deeply eroded tributaries—St. Croix, Chippewa, Trempealeau, La Crosse, Wisconsin, Kickapoo, and Baraboo rivers—while on the east this artesian basin extends to Lake Michigan, and on the south it passes under the Carboniferous deposits. Whether artesian flows may be obtained depends largely upon the elevation above sea level.

Lower Magnesian limestone.—Along the eastern margin several water horizons are found above the Potsdam sandstone. Usually a sufficient supply for domestic use is obtained from the Lower Magnesian limestone, 50 to 100 feet from its top. In a few places this formation gives rise to flowing wells, which in some cases are caused by water from the Potsdam sandstone filling the cracks and fissures of the Lower Magnesian.

St. Peter sandstone.—The second greatest water horizon of the area is the St. Peter sandstone. Although of much less importance than the Potsdam, it furnishes an abundant supply of good water in the eastern and southeastern portions of the district. Northward it becomes of less importance, as it thins out and in many places pinches out entirely. In the southwestern part of the district artesian wells have generally not been obtained, as the rivers cut through well into this formation. However, in these parts the St. Peter sandstone always gives an abundant supply of water for domestic uses.

Galena-Trenton limestone.—The Galena-Trenton limestone, like the Lower Magnesian limestone, yields, in most cases, sufficient water for domestic use. It is seldom necessary to sink the wells more than 100 or 150 feet, and in some cases a sufficient supply for small cities has been obtained at 75 feet. In some localities, notably north of Green Bay, this formation gives rise to flowing wells. In some cases it

appears that the water of this formation is obtained from the underlying St. Peter sandstone, the overlying Niagara limestone, etc.

Niagara limestone.—The Niagara limestone, although hard, compact, and in places highly impervious, furnishes a copious supply. Water is usually obtained from fissures, joint planes, or crevices at a depth considerably less than 200 feet. The formation furnishes requisite artesian conditions, and in a great many instances, particularly along the eastern half of its extent, between Manitowoc and Milwaukee, many fine flows are obtained.

Along the eastern margin of the district the artesian flows are confined to the vicinity of Lake Michigan and to a strip on each side of all the valleys. In the Green Bay and Rock River basins are many of the flowing wells of the interior. The rapid weathering of the impervious Cincinnati shale has reduced this part of the area to such a level that artesian waters might rise to the surface.

Lake deposits.—Besides these deeper-seated waters and the waters coming from the lacustrine deposits along the shores of Lake Michigan and Lake Superior, the area is well supplied with shallow underground waters, commonly known as surface water. Surface wells are found by the score all over the drift area and vary in depths from 10 to 80 feet, and in some case, as along the Kettle Range in eastern Wisconsin, reach a depth of 300 to 400 feet. Many of these wells are not free from contamination, and during the last few years many have gone dry. In 1903, however, nearly all the wells formerly dry had a good supply of water. Along some of the larger streams water is obtained from the river-washed sand and gravel by sinking wells from 10 to 40 feet. Many of these are open or drive wells.

SPRINGS.

Along both sides of the Kettle moraine glacial drift is the source of many fine surface springs and also of subterranean springs that feed so many of the small lakes. Other strong springs from the drift are scattered over the district. In the northwestern part of the area these strong springs flow from the drift overlying the trap rock, and in many cases the water gushes forth in a small stream several feet wide and over a foot deep. So strong are some of these that they have been utilized for water power, as at St. Croix Falls, where a 35-horsepower mill is operated by the water from a spring. Springs have their source in the upper surface of the Cincinnati shale along the east ridge of the Green Bay and Rock River valleys or along the contact of the Niagara limestone and the Cincinnati shale. The impervious shale stops the descending waters flowing through the fissured Niagara limestone, and it escapes at the first opportunity, producing innumerable springs, both great and small, along the entire extent of this marked and important contact. Much of the water from this

source never comes to the surface near the contact but flows underground through the sand and gravel beneath the red clay and gives rise to some of the fountains found east of Fond du Lac. The other important horizons are confined chiefly to the contact of the Potsdam sandstone and Lower Magnesian limestone and to the contact of the Galena-Trenton limestone and the St. Peter sandstone. In many cases in western Wisconsin springs also arise from various horizons of the Potsdam sandstone.

MINERAL WATERS.

Along the eastern margin a considerable number of strong springs flow from the Niagara limestone, of which the most noted are the famous Waukesha Springs, whose waters have long been on the market. Although considerable water is being bottled, this industry is still in its infancy and waiting for development. At present there are innumerable springs moderately charged with mineral matter and well adapted for certain medical uses, whose waters have never been analyzed. Most of the springs within the area contain a small amount of mineral matter averaging approximately 300 parts per 1,000,000. Other springs of a much higher degree of purity are found, one containing only a little over two grains per gallon, three-fourths of which was in the form of carbonates. Most of the springs thus far have received but little attention outside their use for domestic purposes. In some cases springs have been and are being used for public water supplies, as at Lancaster, Wis., where a spring with a daily capacity of 2,160,000 gallons furnishes the entire city with wholesome water. The deeper seated waters are used chiefly for city water supply and for various manufacturing industries.

In a few cases where the waters have rare medical properties, as at Sheboygan and Prairie du Chien, Wis., the waters have been bottled and placed on the market or used for special treatment at the sanitarium. The amount of mineral matter contained in the well water for the most part is comparatively small, in some cases being as low as 7 grains per gallon and seldom being more than 50 grains per gallon. However, in a few cases the amount exceeds 600 grains per gallon, while at Osceola, on Silver Brook farm, the water from the Potsdam sandstone at a depth of 50 feet contained a total of 993.9 grains per gallon, made up as follows: $NaCl$, 320.58 grains; $CaCl_2$, 583.1 grains; $MgCl_2$, 18.98 grains; $CaSO_4$, 62.20 grains; iron and aluminum oxides, 2.97 grains, and silica, 6.07 grains. Concerning this water, which has recently been analyzed, J. H. Long writes as follows:

This water is a very unusual and peculiar one because of the presence of so large an amount of calcium chloride. I do not recall any mineral spring in this country which resembles it in this respect, but some of the so-called bitter springs of Germany have a somewhat analogous nature. The water is too highly charged with mineral matters to be used in quantity as a medical beverage, but in special cases and for a limited time it might be profitably used. Such waters are often used for

baths; in fact, that is their main application, and medical men could suggest the cases in which such a water as this one could be used properly.

There is no doubt that in the future these various fields will be greatly extended and many of the cities now without a system of waterworks will soon draw upon the underground channels for their supply.

A list of the springs which reported sales of mineral water in 1902 is given below:[a]

Allouez Magnesia Springs, Green Bay, Brown County.
Aurelian Spring, Palmyra Springs, Jefferson County.
Bay City Spring, Ashland, Ashland County.
Bethania Mineral Springs, Osceola, Polk County.
Chippewa Spring, Chippewa Falls, Chippewa County.
Darlington Mineral Spring, Darlington, Lafayette County.
Fort Crawford Springs, Prairie du Chien, Crawford County.
Lebens Wasser Mineral Spring, Green Bay, Brown County.
Nee-Ska-Ra Mineral Spring, Wauwatosa, Milwaukee County.
Rainbow Mineral Spring, Wautoma, Waushara County.
Salvator Mineral Spring, Green Bay, Brown County.
Sanitas Fountain, Oshkosh, Winnebago County.
Shealtiel Mineral Spring, Farmington, Waupaca County.
Sheboygan Mineral Spring, Sheboygan, Sheboygan County.
Silver Sand Spring, Milwaukee, Milwaukee County.
Slauson Mineral Spring, Racine, Racine County.
Solon Springs, Upper St. Croix Lake, Douglas County.
St. John Mineral Springs, Green Bay, Brown County.
Waukesha Springs, Waukesha County:
- Acme Spring.
- Almanaris Springs.
- Anderson's Waukesha Spring.
- Arcadian Spring.
- Bethesda Mineral Spring.
- Fountain Spring.
- Henk Mineral Spring.
- Hygeia Spring No. 2.
- Minniska Mineral Spring.
- Siloam Mineral Spring.
- Silurian Mineral Spring.
- Sotarian Spring.
- Waukesha Imperial Spring.
- Waukesha Lithia Spring.
- White Rock Mineral Spring.

The reported sales reached a total of 5,982,948 gallons, with a value of $1,199,473.

PRINCIPAL PUBLICATIONS.

Artesian wells, by T. C. Chamberlin: Wisconsin Geol. Survey, 1873–1879, vol. 1, pp. 689–701, 1883.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 151–157.

Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, pp. 65–66.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, p. 996.

LOWER MICHIGAN.[a]

TOPOGRAPHY.

Lower Michigan is mainly a rolling area, with an elevation ranging generally between 600 and 1,000 feet above sea level. In the southern half of the peninsula the general level is broken by relatively low morainal ridges left by the glaciers which once covered the region. In the northern portion of the State the morainal deposits are much more pronounced, occurring as prominent northeast-southwest ridges, and in places rising to heights of over 1,500 feet. The topographic features are, in fact, due almost entirely in most areas to the accumulation of glacial drift, which may reach a thickness of 800 feet or more, and completely buries the irregularities of the underlying rock.

GEOLOGY.

Leaving out of account the glacial drift which has been mentioned above, and considering only the consolidated rocks, the Lower Peninsula of Michigan is structurally a great oval basin, toward which the rocks dip from all sides. The geographic center is in Gratiot County, about 50 miles north of Lansing. The strata are mainly of Carboniferous age, but a rim of Devonian rocks extends along the shores of Lakes Michigan and Huron from Mason County, on Lake Michigan, to Alpena County, on Lake Huron. Small areas or strips of Devonian rocks occur along the rim of the coal basin, in the extreme southeastern and southwestern portions of the State. A few dolomitic and other beds of Silurian age also occur at the extreme northern tip of the peninsula and along the shores of Lake Erie to the southeast.

The general character of the basin and the outcrop of its beds is shown in fig. 38, while fig. 39 shows a cross section of the basin from west to east.

UNDERGROUND WATER SUPPLIES.

SUPPLIES OF THE DRIFT.

Eastern shore district.—This district embraces the eastward-sloping strip lying between the moraines and the shores of Lakes Huron, St. Clair, and Erie, from Saginaw Bay to the southern limits of the State.

The surface deposits of the region, except in some of the valleys

[a] Compiled mainly from report by A. C. Lane on Water Resources of the Lower Peninsula of Michigan, Water-Supply and Irrigation Paper U. S. Geol. Survey No. 30, 1899. For facts relating to the Upper Peninsula of Michigan, see the description of the Wisconsin district, pp. 233 to 241.

and in the old beaches along the lakes, are predominantly clay. The clays yield no water, but small supplies, which are liable to fail in times of drought, are found in pockets of gravel or sand in the clay, and a water-bearing layer commonly occurs at the contact of the drift with the underlying rock. Near the moraine the water-bearing sands

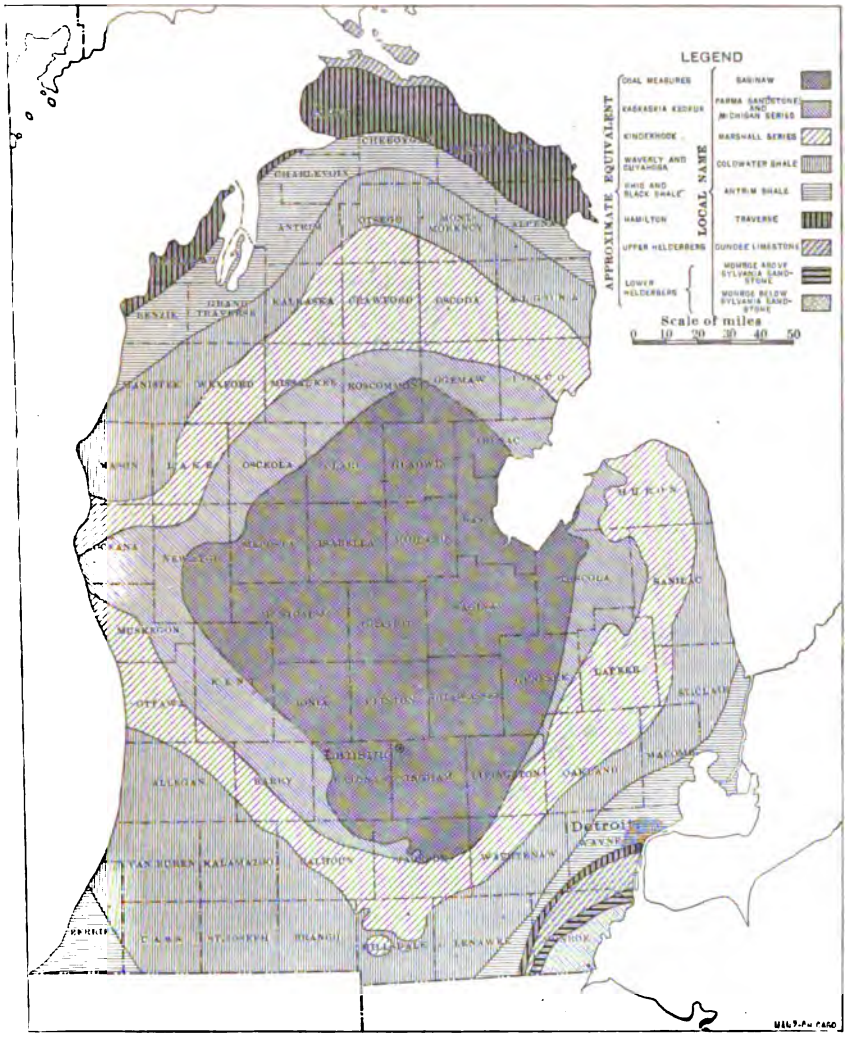


FIG. 38.—Geologic sketch map of lower Michigan.

are more numerous, and at least one city, Ypsilanti, obtains its public supply from wells in the drift. The waters in the upper part of the drift are of good quality, but in the lower part they are often charged with salt and other minerals, or with gas derived from the underlying rocks from which the waters come. Some of the wells flow. In the stream and other gravels and sands of the valleys and in the sandy

beaches bordering the lakes good waters are often obtained by shallow wells, but the wells are liable to fail in especially dry seasons.

Saginaw Valley district.—This district includes the drainage basin of Saginaw River and portions of adjacent regions. The surface is flat, the streams generally flowing in shallow valleys. It is covered with clayey drift or hardpan, or with clays deposited in a glacial lake, the deposits averaging from 80 to 100 feet. Sand ridges occur near the lake.

The sand ridges carry water in moderate amount and subject to contamination. Sands and quicksands within the clay frequently yield somewhat hard water, which may even flow. The wells are easily clogged. Water equally good and with a greater head can be obtained by drilling into the underlying sandstones. Some of the drift wells

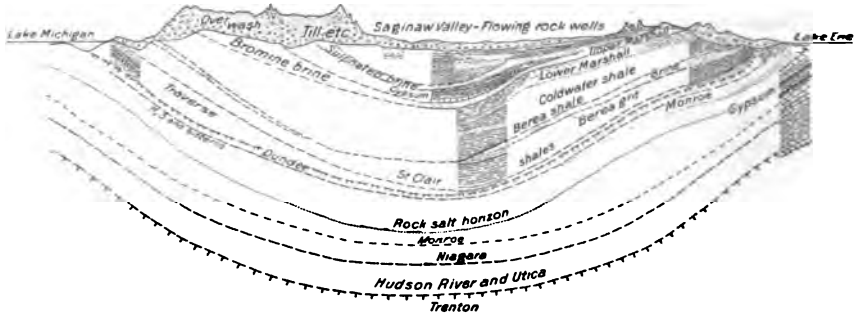


FIG. 39.—Section across lower Michigan.

carry calcium sulphate derived from gypsum in the drift, and gas is not uncommon.

Northeastern shore district.—This area embraces the drainage area of the Thunder Bay River and a few small streams emptying into the lake in its vicinity. To the southwest lies a high moraine containing some of the highest land in the State. The surface consists of a series of morainal ridges with intervening tracts covered by sand. Water can be obtained from this sand, though it frequently lies at a considerable depth. Springs emerge where the clay layers are cut by streams. Deep wells in the drift find sands with water, which will sometimes rise to the surface from beneath till and clays. The water is quite hard, but is otherwise generally excellent. It is hardly suitable for use in boilers.

Western shore district.—This district lies along the northwest and west coast of the peninsula, and extends inland far enough to include a portion of the high morainal ridges. The surface is drift, the rocks frequently lying from 500 to 600 feet below the surface. The drift is generally clayey, but contains many beds of sand, some of which can be reached by driven wells. Sometimes, in the more porous drift, wells

must be sunk 300 to 400 feet to obtain water. The waters are seldom saline.

North-central district.—This area includes the upper portions of the drainage basins of Manistee, Muskegon, and Au Sable rivers and adjacent areas. The surface consists mainly of sandy drift, yielding water to shallow driven wells. In the few deep wells that have been sunk, the thickness of the drift is found to be 350 to 500 feet, or more.

Saginaw moraine district.—This area includes the region of the Saginaw moraines in the central part of the State, and southwest of the Saginaw Valley district. The region is one of morainal drift, the deposits being generally from 100 to 500 feet thick. The composition of the drift is very variable, and many water-bearing sands occur. The underlying rock furnishes a reliable source of water, and a few wells have been drilled into it. Wells some times flow in the lower districts.

South-central district.—This district includes the land in the central portion of the State lying south of the Saginaw district. The drift is usually thick. The water conditions are much the same as in the Saginaw district.

ROCK WATERS.

Trenton limestone.—This limestone has been penetrated at Monroe, Wyandotte, Dundee, Blissfield, and Dowagiac. It yields a strong, but impure brine, with traces of oil and gas.

Hudson and Utica shales.—These shales have been penetrated by a few wells drilled to the Trenton limestone. They are similar to the Coldwater and St. Clair shales.

Niagara and Clinton limestones.—These are penetrated only in southeastern Monroe County, southwest of Kalamazoo and north of Frankfort. Water was obtained from these beds at Dundee and Britton, but they are otherwise undeveloped.

Monroe and Salina beds.—These beds are mainly buff marls, dolomites, and rock salt, but at the top there is a persistent sandy bed yielding much water. The waters are mainly brines, but fresh water has been found in one or two horizons near the outcrop.

Dundee limestone.—This is a light limestone full of flint and carries considerable quantities of water charged with salt, hydrogen sulphide, and other minerals, making it the source of some of the most valuable mineral water of the State.

Traverse series.—This series consists of alternations of limestones and shales with an aggregate thickness of 500 feet or more. In the northern part of the State the series yields water freely in some cases, and even in the southern part water is obtained from several of the limestones.

Antrim shales.—These are blue to black shales underlying the Berea grit. They yield neither fresh water nor brines in any amounts.

Berea shale and grit.—Below the Coldwater shales lies about 130 feet of black or chocolate shales, while beneath these in turn is about 60 feet of white to brown sandstone yielding at any considerable depth pure brines with some gas.

Coldwater shales.—These shales are generally fine grained, micaceous, and bluish. They carry little water, but small amounts are obtained from sandy layers in a few wells.

Lower Marshall sandstone.—This formation is about 260 feet in thickness and consists of ferruginous, sandstones, flags, etc., underlying the Upper Marshall sandstone. It yields good water, rather chalybeate.

Napoleon or Upper Marshall sandstone.—This sandstone, which belongs to the Carboniferous system, is rarely less than 50 feet thick, and underlies the drift in a broad belt extending from Saginaw Bay southwest to the southern boundary of the State in Hillsdale County. It yields copious supplies of fresh water through many flowing wells that have been sunk to a depth of about 250 feet through the western part of Huron County to Sebewaing. Wells sunk to greater depths, if the rocks of the Michigan series are not properly cased off, yield salt water. Southwest of Lansing and Mason the water is generally good.

Michigan series.—This series consists of shales, hydraulic limestones, and gypsum beds immediately overlying the Upper Marshall sandstone. The waters are almost universally salt or bitter, and must be carefully cased off in all wells going to a deeper horizon for fresh waters. This series can be traced beneath the drift by the composition of the water. Included in the Michigan series is the Grand Rapids limestone.

Parma sandstone.—The Parma sandstone unconformably overlies the Michigan series and is generally separated from the Marshall by a thin bed of shales, but in places merges with it. The waters of both the sandstone and limestone are generally hard, though in some cases they are pure. They have seldom been used for brines.

Overlying the Parma is a series of shales, sandstones, coal, fine clays, iron ores, etc., yielding much water of a highly mineralized character and frequently of medicinal value. Wells are very numerous throughout the region.

MINERAL SPRINGS.

The following 28 springs reported sales in 1902, amounting to 8,653,690 gallons, with a value of $275,763.[a]

Alma-Bromo Spring, Alma, Gratiot County.
Andrews Magnetic Mineral Springs, St. Louis, Gratiot County.
Bromo-Hygeia Mineral Well, Coldwater, Branch County.
Clementine Spring, Mount Clemens, Macomb County.
Cooper Farm Spring, Birmingham, Oakland County.
Eastman Mineral Springs, Benton Harbor, Berrien County.
El Cajon Mineral Springs, El Cajon Beach, Alpena County.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

Frankfort Springs, Frankfort, Benzie County.
Magnetic Mineral Spring, Spring Lake, Ottawa County.
Midland Mineral Springs, Midland City, Midland County.
Moorman Springs, Ypsilanti, Washtenaw County.
Mount Clemens Sprudel Water, Mount Clemens, Macomb County.
No-che-mo Mineral Spring, Reed City, Osceola County.
Original Mount Clemens Mineral Spring, Mount Clemens; Macomb County.
Pagoda Spring, Mount Clemens, Macomb County.
Plymouth Rock Well, Plymouth, Wayne County.
Ponce de Leon Springs, Paris Township, Kent County.
Premier (formerly Excelsior) Mineral Springs, Benton Harbor, Berrien County.
Prosit Flowing Well, Oak Grove, Flint, Genesee County.
Red Cross Mineral Well, Big Rapids, Mecosta County.
Royal Oak Mineral Springs, Royal Oak, Oakland County.
Salutaris Spring, St. Clair Springs, St. Clair County.
Sanator, formerly Americanus Well, Lansing, Ingham County.
Sterling Spring, Crystal Falls, Iron County.
Victory Springs, Mount Clemens, Macomb County.
Welcome Island Lithia Springs, near Pontiac, Oakland County.
Wurtzel's Mineral Spring, Thomastown, near Frost, Saginaw County.
Zauber Wasser Springs, Hudson, Lenawee County.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 145–150.

Water resources of the Lower Peninsula of Michigan, by A. C. Lane: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 30, 1899.

Lower Michigan mineral waters, by A. C. Lane: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 31, 1889.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 51–54.

Michigan [well records], by W. F. Cooper: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, pp. 489–512.

ILLINOIS.

By Frank Leverett.

INTRODUCTORY STATEMENT.

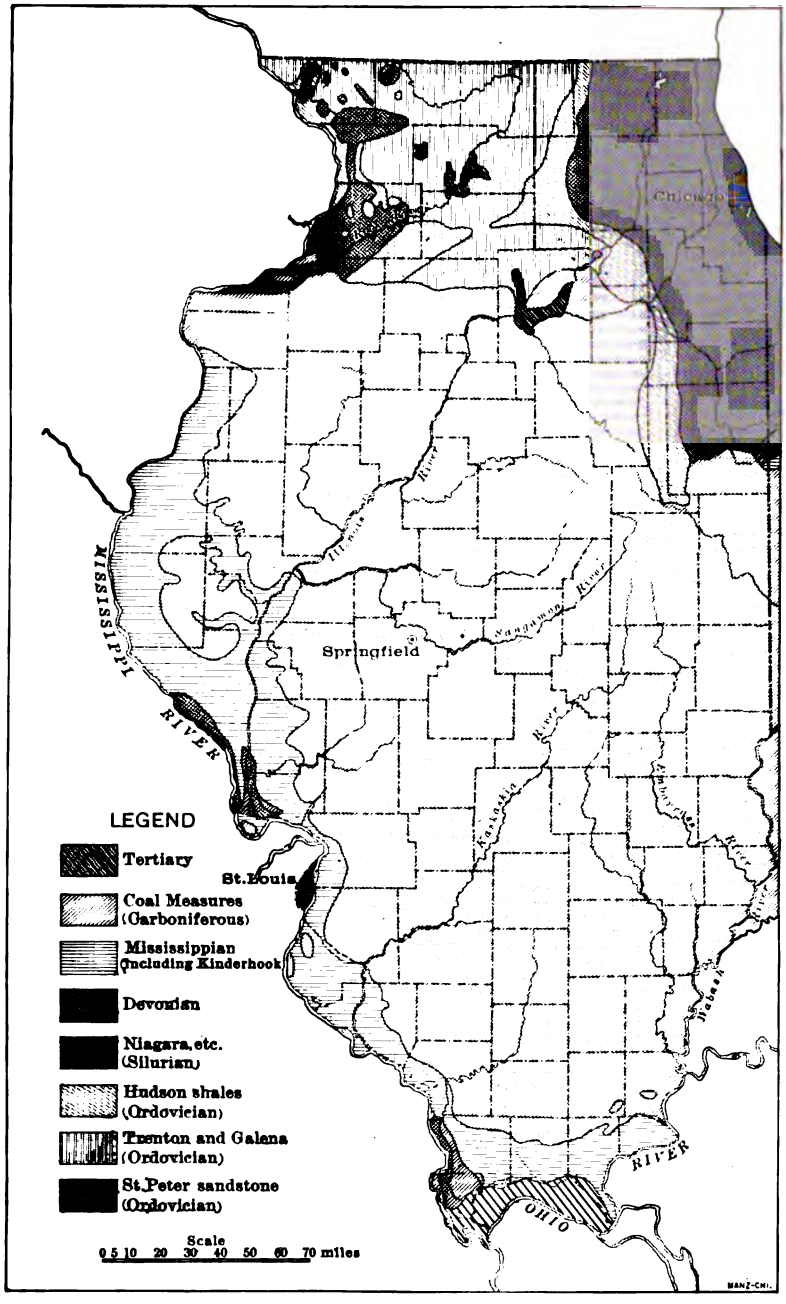
This brief discussion of water conditions in Illinois is restricted chiefly to the relative value of the several geologic formations as water-bearers. Several other topics relating to water conditions, namely, rainfall, drainage basins, run-off and regimen of streams, navigation, water power, city, village, and rural water supply, artesian wells, and water analyses have been discussed by the author in some detail in earlier reports of this Survey.[a] A chemical survey of the water supplies of Illinois is the topic of a report of 98 pages by Dr. A. W. Palmer, issued by the University of Illinois in 1897, and a later report of 254 pages by the same author giving the results of several thousand analyses has been issued by the University within the last year.

GEOLOGIC COLUMN.

The rock formations either exposed or within reach of the wells of Illinois extend through the Paleozoic series from the Cambrian to the later part of the Carboniferous, including perhaps the Permian, as indicated in the table on page 249. There is then a wide gap, the next formation being the Cretaceous, which has been found to underlie the Ohio River at Cairo, but is not known to be exposed in the State.[b] On the borders of the Ohio in southern Illinois are deposits of Tertiary age, consisting mainly of clay, micaceous sand, and a ferruginous, pebbly conglomerate. These deposits are probably separated from the Cretaceous by an interval of some consequence, and are known to be separated from the next later formation developed in Illinois, the Pleistocene, by a wide interval. In the table on page 249 the several drift sheets of the Pleistocene are presented because these divisions of the drift are of importance in discussing the water conditions. They should not, however, be given the rank of the divisions in the Paleozoic series. The table begins with the newest formation and extends to the oldest,

[a] Water resources of Illinois, Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, pp. 695-849. The Illinois Glacial lobe, Mon. U. S. Geol. Survey, vol. 38, 1899, 817 pp.

[b] Nickles, J. M., Report of Illinois Board of World's Fair Commissioners, p. 217, Springfield, 1895. H. W. Rokker, State printer.



GEOLOGIC SKETCH MAP OF ILLINOIS.

this being the order in which they are met by the drill. The extent of the several formations which lie beneath the Coal Measures has not been tested by a sufficient number of borings to permit even approximate calculations. The figures given are largely conjectural.

Geologic column of Illinois.

Formation.	Extent in State.	Thickness.
	Square miles.	*Feet.*
Wisconsin drift sheet (Pleistocene)	19,000	5–200
Iowan drift sheet and main loess deposit (Pleistocene)	[a] 45,000	5–60
Illinoian drift sheet (Pleistocene)	53,000	10–200
Kansan drift sheet (Pleistocene)	±1,800	±10–100
Pre-Kansan drift sheet? (Pleistocene)	?	?
Tertiary deposits (perhaps of two or more epochs)	700	±10–100
Cretaceous deposits	±10	?
Permian beds?	?	?
Upper Coal Measures (Carboniferous)	19,000	±10–700
Lower Coal Measures (Carboniferous)	36,000	±10–1,000
Conglomerate sandstone (Carboniferous)	±30,000	20–500
Chester group (Carboniferous)	±15,000	10–800
St. Louis group (Carboniferous)	±30,000	20–250
Keokuk group (Carboniferous)	±30,000	100–200
Augusta or Burlington limestone (Carboniferous)	±30,000	25–200
Kinderhook group (Carboniferous)	±30,000	50–330
Black slate (Devonian)	±35,000	10–60
Hamilton limestone (Devonian)	±35,000	10–120
Corniferous limestone (Devonian)	?	5–25
Oriskany sandstone (Devonian)	?	40–200
Niagara group (Silurian)	±45,000	70–400
Hudson River group (Ordovician)	±48,000	40–275
Trenton group (Ordovician)	±55,000	45–450
St. Peter sandstone (Ordovician)	±55,990	40–420
Lower Magnesian limestone (Cambrian)	56,000	±200–1,000
Potsdam sandstone (Cambrian)	56,000	±300–1,000

[a] The loess covered all of Illinois outside the Iowan drift, but was in part taken up by the Wisconsin ice sheet.

The entire thickness of the Paleozoic series of rocks ranges probably from a little more than 2,000 to possibly 6,000 feet. Two borings just outside the State at Burlington, Iowa, and St. Louis, Mo., are reported to have reached pre-Cambrian rocks at 2,400 and 3,800 feet, respectively. So far as known to the writer no wells in the State have reached the bottom of the Paleozoic system, though several have been sunk to depths of more than 3,000 feet. One at Aledo, only a

few miles from the Burlington well, terminated in Potsdam sandstone at a depth of 3,115 feet, and one at the Jacksonville waterworks has a depth of 3,028 feet. Probably the deepest boring in the State is one at St. John, Perry County, which reached a depth of 3,750 feet, and may not have entered the Potsdam sandstone.

PRINCIPAL WATER-BEARING FORMATIONS.

Potsdam sandstone.—The Potsdam sandstone is by far the most capacious water-bearing formation in the State. It is a porous rock, and as it is very thick and outcrops over a large area in Wisconsin, the intake is sufficient to give an unlimited supply of water to wells which reach this formation in Illinois. It is, however, within easy reach of wells only in a few counties in the northern and western portions of the State. In the northern part it has been reached by numerous wells as far south as Illinois River and is probably within reach of wells in the portion of the State west of the south-flowing part of the river. On the north border of the State the water is sufficiently fresh in most cases to be suitable for drinking, but upon passing southward it becomes brackish and in many cases unsuitable for domestic use.

St. Peter sandstone.—Next after the Potsdam sandstone should be mentioned the St. Peter sandstone, which is the source of supply for a large number of artesian wells in the northern and western parts of the State. The quality of water obtained from it is usually good, and is adequate to the needs of the smaller cities and towns. But in the larger cities, especially in Chicago, it can scarcely furnish the amount of water needed, and for that reason many wells have been sunk to the Potsdam formation. The porous or water-bearing portion of the formation varies from a thickness of 40 feet up to 150 feet or more.

In several instances wells have obtained good supplies of water from the sandstone beds which appear in the Lower Magnesian formation between the Potsdam and St. Peter sandstone. It is found that this formation is made up more largely of sandstone beds in northern Illinois than in the region of outcrop in Wisconsin, as may be seen by records of wells published in the reports by the author above cited.

Galena limestone.—The Galena limestone is very largely of porous rock, and in the region of outcrop in northern Illinois is a good water-bearer. The drill has shown that parts of it, buried deeply beneath later formations in western Illinois, will yield strong artesian wells, so that it is unnecessary at such points to sink to the St. Peter or lower formations.

Niagara limestone.—The Niagara limestone is another great water-bearer, not only in northern Illinois, where it immediately underlies the drift, but often also when under the cover of other rocks. The water seems in many cases to be traversing the formation in streams

or veins, probably along fissures, and the depth to these veins may vary greatly in neighboring wells. The fissures were probably opened widely by atmospheric action before the formation was buried beneath the drift or older rocks. An objectionable feature of many wells obtaining water from the Niagara limestone is the presence of sulphureted hydrogen, formed from the decomposition of pyrites present in the limestone. There are, however, numerous wells in which this is not a pronounced feature, and the water is otherwise palatable and wholesome.

Devonian limestones.—The Devonian limestones are ordinarily poor water-bearers compared with the Niagara limestone, yet, in certain localities, they afford sufficient water to supply local needs. Their outcrop is also much more restricted than that of the Niagara, being confined to small areas in the western and southern parts of the State.

St. Louis limestone.—The limestone formations of earlier Carboniferous age have outcrops over several counties in western and southern Illinois, and, though not great water-bearers, are drawn upon largely where the glacial deposits are either wanting or are too thin to supply the water.

Chester sandstone.—The Chester group of southern Illinois contains sandstones which are generally good water-bearers, but their outcrop is limited and they soon pass to so great a depth as to make drilling to them expensive. The water in the deep-lying beds is also liable to be brackish or unsuitable for domestic use.

"*Conglomerate*" *sandstone.*—The "Conglomerate" sandstone which underlies the Coal Measures in central, eastern, and southern Illinois is not likely to become a valuable source of water for domestic use, for it is a very thin formation in the northern part of its field, and where thick in the southern part is generally buried deeply under Coal Measures. In the latter situation it is usually charged with salt water.

Coal Measures.—The sandstone beds of the Upper and Lower Coal Measures constitute probably half the thickness of the formations, and they are generally permeated with water which, however, is suitable for domestic use only at a few horizons, usually within 200 feet of the surface, for at other horizons and at greater depth there are often either salt or sulphates to render the water objectionable. These formations, however, usually supply the needs of residents in places where the drift cover does not furnish a sufficient amount of water.

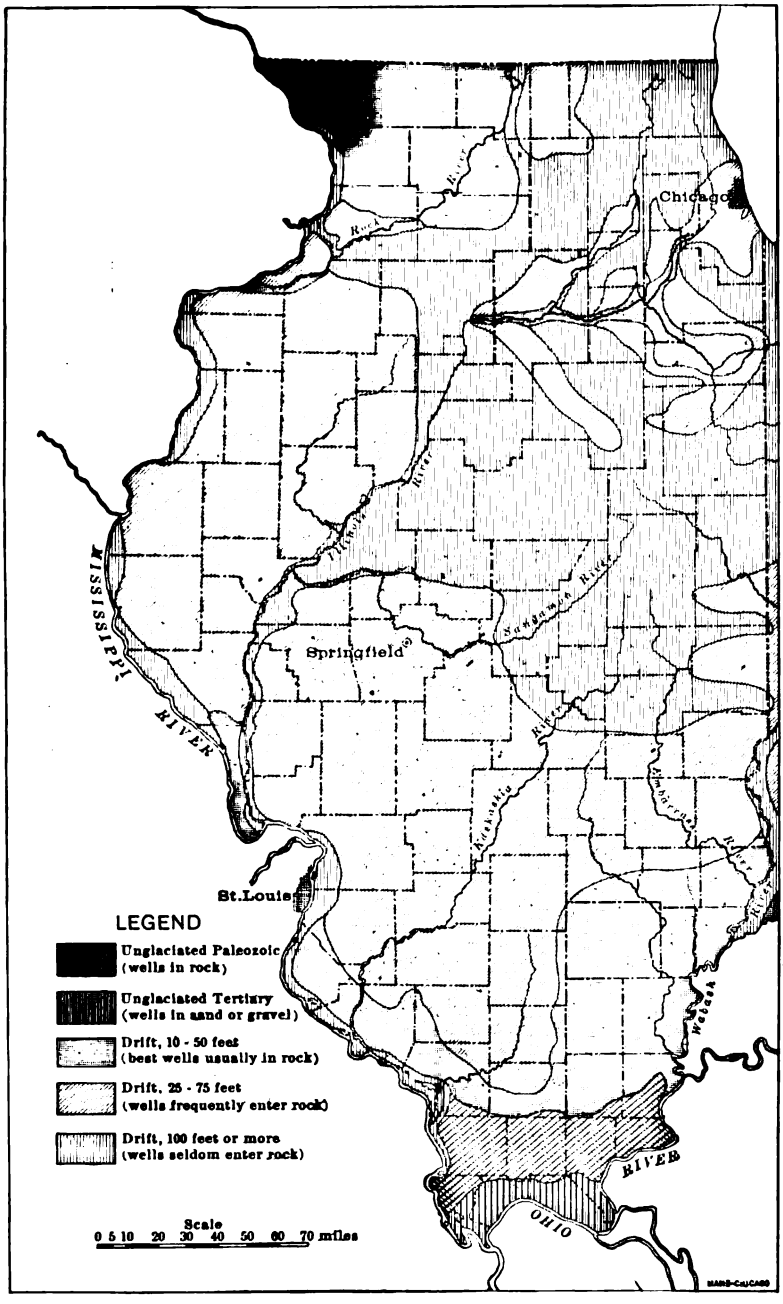
Tertiary deposits.—The Tertiary deposits are of limited extent and shallow depth and afford a very unimportant part of the water supplies of the State. In the region where they occur wells are often sunk to the underlying limestone.

Glacial deposits.—The glacial deposits are probably more often drawn upon than all other formations combined, for they are surface formations and the water is reached by wells of moderate depth such as

nearly every resident can afford. There are probably more than a half million wells in these deposits. The complexity of the glacial formations, however, is such that in a large part of the glaciated area it is difficult to forecast the results of boring into them. It is estimated that about 70 per cent of the glacial drift is a compact clayey material affording very little water, except by slow seepage. The remaining 30 per cent would, if distributed to the best advantage, be adequate to the needs of residents. But unfortunately there are tracts of considerable extent in which the drift is almost wholly of a clayey constitution, while other tracts have a superabundance of water-bearing material. A somewhat detailed study of these deposits has shown that the distribution of the sand and gravel beds depends to a large degree upon the drainage conditions attending the melting of the ice. In the repeated advances which the ice made into this region the sand and gravel beds distributed by the water from the melting of a given ice sheet were overridden and buried deeply in places by the deposits from a later ice sheet. Then, too, there appear to have been minor oscillations of the ice front in each stage of glaciation by which sand and gravel beds, which had been spread out at the edge of the ice sheet, were covered by clay deposits laid down during the readvance of the ice. In western and southern Illinois the sand and gravel found in the drift seem to have been deposited as the result of these minor fluctuations, for they are distributed in very irregular and limited areas. In central, eastern, and northeastern Illinois there are, in addition to such beds, more extensive ones lying between the main drift sheets. It is also found that throughout the State a large amount of sand and gravel and abundance of water are usually found along the line of pre-Glacial valleys. In the northern part of the State, north from a line running from Rock Island to Watseka, there is a large amount of gravelly and sandy drift at or near the surface. Farther south the surface sand and gravel are generally restricted to the valleys of the main drainage lines. Pl. XVI indicates the relation of the drift to the wells. It shows the areas in which wells are obtained almost wholly from the drift, areas in which drift and rock wells are each used extensively, and areas in which it is generally necessary to go into the rock to obtain water. There are many weak wells within the areas of thick drift, but in the great majority of cases farmers have penetrated to water-bearing beds or veins, which afford an adequate supply.

LOCALITIES FAVORABLE FOR ARTESIAN WELLS.

Artesian wells as here discussed include only wells which overflow, whether from the rock or from the glacial formations. It should be understood, however, that a large number of wells not classed as artesian are under the same hydrostatic pressure as those that flow and the water rises to a similar altitude above sea level.



MAP SHOWING THICKNESS OF DRIFT IN ILLINOIS.

The artesian wells obtained from the several rock formations in northern and western Illinois must generally be situated on ground less than 700 feet above sea level, for it is well established that water will not rise above that height, except in the extreme northern part of the State or in localities where the greater head is obtained from drift formations, which constitute the main source of supply for the wells. In southwestern and southern Illinois the ground must be considerably lower than in northern and western Illinois to obtain a flow. In the latitude of St. Louis, and south from there, the head is generally as low as 500 feet above tide, and flows are obtained only at a few points, there being a less uniform head or hydrostatic pressure than in the northern and western parts of the State. The most favored part of the State for deep artesian wells is that lying north and west of Illinois River. The following section (fig. 40) is along a line from Wisconsin River in western Wisconsin southward to Cap au Grès near the mouth of Illinois River through a region where artesian wells are very successful. It will be observed that northward from Aledo the section shows but one shale bed—the Hudson—and this is wanting north of Galena, but south from Aledo the Kinderhook, Devonian, and Coal Measures shales comprise a considerable portion of the section. It is thought that the intake is not restricted to the outcrop of the sandstone in Wisconsin, but that the limestones and other pervious beds farther south take in a large amount of water.

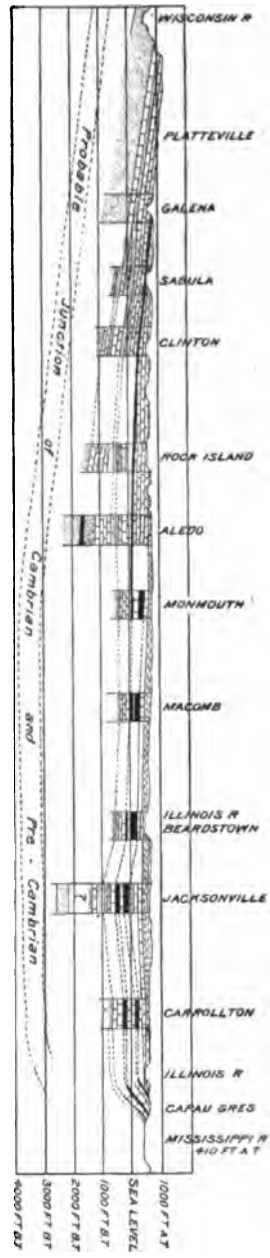


FIG. 40.—Section from the Wisconsin River in western Wisconsin southward to Cap au Grès, near the mouth of Illinois River. The black bands represent shales; other beds are fair to good water bearers.

There are only a few small areas in Illinois in which the drift furnishes flowing wells. These areas are usually on the slopes of moraines, or along valleys in which there is a thick filling of drift. The intake appears to be on the moraines or possibly on outlying gravel plains in the first instance, and on higher ground bordering valleys in the second instance. In these wells, as in those which obtain their supply from the rock, the rise of water, or hydrostatic pressure, is in many cases

no greater than in neighboring wells that do not overflow, the overflow being due to the low altitude of the surface. The largest flowing well district is in a basin lying on the north slope of a morainic system in Iroquois County and border portions of adjacent counties in eastern Illinois, and comprises an area of about 500 square miles. There is a smaller district with exceptionally strong flows around Potomac, in northern Vermilion County. Other small districts occur near Plattville, in Kendall County; near Earlville, in northern Lasalle County; near Sycamore, in northern Dekalb County; near Palatine, in northern Cook County, and along Salt Creek Valley, in northern Cook and eastern Dupage County. There are a few flowing wells along the north fork of Chicago River, in northern Cook and southern Lake counties. Flowing wells are also common in low-lying tracts among moraines of Lake, McHenry, and Kane counties. The combined area of all these small districts will probably not greatly exceed that of the Iroquois district (500 square miles). Occasional flowing wells are scattered over the central part of the State, chiefly along river valleys, and there are very few in the western and southern portions in similar situations.

WATERS IN RELATION TO HABITATION.

The census of 1900 gives Illinois a population of 4,821,550, which warrants the assumption of a present population of about 5,000,000. About half of this population derives the supply for drinking and many other domestic uses from surface water, Lake Michigan furnishing water for the 2,000,000 or more people of Chicago, and several other small cities along the lake, and the streams of the State furnishing a supply for about 300,000 people living in the small cities and villages. It is estimated that about a half million people obtain their drinking water from wells of considerable depth. There thus remains about 2,000,000 people who are supplied from wells of shallow depth. A small part of the population, residing principally in the driftless parts of the State, depend entirely upon rain water collected in cisterns, and rain water is used to a small extent in every community throughout the State for drinking water, and is used extensively for other domestic purposes. Spring water is also in use to a very limited extent throughout the State.

The chemical survey of the waters of the State instituted at the University of Illinois in 1895, and conducted by Prof. A. W. Palmer, has called attention to the quality of the water from the several sources in use. Up to the present time about 11,000 sanitary analyses and 500 mineral analyses have been made, representing conditions in 100 of the 102 counties and about 500 cities, villages, and hamlets. From the

latest report,[a] covering the period 1897 to 1902, inclusive, the following results of the survey are taken. The rain water in use by the residents is seldom properly filtered and the ordinary cistern filter, "as commonly managed or rather neglected, frequently is almost worse than useless, inasmuch as it soon becomes surcharged with matters which it has removed from some of the water, and then, instead of purifying the water that subsequently passes through, often becomes a source of offense if not of danger."

"In general, water taken from lakes, from streams, or from the ground, when these sources of supply are in their original or natural condition, is perfectly wholesome and unobjectionable, but with increasing population and longer occupancy of the ground the conditions change and contamination becomes inevitable." For this reason Professor Palmer remarks that it would be best for even the people of the smallest towns to use for drinking purposes only the water supplied by one general plant, the sanitary condition of which could and should be thoroughly and periodically investigated by experts acting under the direction of a water commission or the State board of health.

This chemical survey has shown that the normal shallow drift waters contain chlorides, sulphates, carbonates, and silicates of calcium, magnesium, potassium, and sodium, with minute quantities of iron and aluminum compounds, together with considerable quantities of nitrates, but only minute quantities of saline ammonia and albuminoids; organic matters are almost entirely absent; nitrites are frequently present in notable quantity. The normal deep drift waters contain in general the same mineral salts as the shallow waters, but usually the quantity of iron is considerable, and the nitrates are either entirely absent or present in but minute quantity, while free ammonia is abundant and albuminoids are present in considerable quantities. "Oxygen consumed" is high, and the water residue blackens upon being heated, showing that it contains much organic matter. The waters from shallow wells are well aerated and are clear, sparkling, cool, and of agreeable taste; those from the deeper wells contain little or no oxygen, possess in many cases a disagreeable taste, due to the presence of marsh gas, accompanied occasionally by minute quantities of sulphureted hydrogen, and are either turbid or become turbid quickly on exposure to air, owing to the oxidation of the iron carbonate which they contain and the consequent precipitation of insoluble ferric compounds.

"Although these unpleasant characteristics of the deep drift waters give rise to much prejudice and objection to their general use for drink, nevertheless, from the sanitary standpoint they are usually to

[a] Chemical Survey of the Waters of Illinois. Report for the years 1897-1902, by Arthur William Palmer. Published by the University, 1903, 254 pages.

be preferred to the clear and palatable waters of the shallow wells, since the evidence of numerous analyses shows that they are less subject to pollution with refuse animal matters than are the latter, while the organic matters which they contain are derived from buried vegetable remains and are comparatively harmless.[a]

MINERAL SPRINGS.

Though not so abundant as in more rugged areas, springs are nevertheless numerous in Illinois. Those of the drift are probably the most abundant numerically, but the individual springs are generally small, sometimes being mere seeps. Such waters vary in character according to the constitution of the drift, but in general they are hard, and frequently carry considerable iron in solution. In the Coal Measure rocks they are very often highly charged with iron sulphate or carbonate, salt, hydrogen sulphide, etc., while in the limestone the waters are generally very hard. Springs are numerous, and sometimes of considerable size in the limestones and older sandstones, especially along the bluffs of Mississippi River.

A considerable number of the mineral springs are the sites of resorts of more or less importance. Many report sales of water for medicinal or table purposes. The 22 springs reporting to the United States Geological Survey in 1902 are as follows:[b]

Abana Spring, Libertyville, Lake County.
Anna or Cave Mineral Springs, Anna, Union County.
Aqua Vitæ Mineral Springs, near Maquon, Knox County.
Aurora Lithia Spring, Montgomery, Kane County.
Black Hawk Springs, Rock Island, Rock Island County.
Blue Grass Springs, Montgomery, Kane County.
Cumberland Mineral Spring, near Greenup, Cumberland County.
Deer Lick Mineral Spring, Dearfield, Lake County.
Diamond Mineral Spring, Grantfork, Madison County.
Elmhurst Mammoth Spring, Elmhurst, Dupage County.
Glen Flora Mineral Springs, Waukegan, Lake County.
Gravel Springs, near Jacksonville, Morgan County.
Macinac Mineral Spring, Woodford County, near Carlock.
Magnesia Spring, Montgomery, Kane County.
Min-ni-Ni yan Spring, Bristol, Kendall County.
Mokena Mineral Spring, Mokena, Will County.
Original Springs, Okawville, Washington County.
Perry Mineral Springs, Perry Springs, Pike County.
Red Avon Mineral Spring, Avon, Fulton County.
Sanicula Springs, Ottawa, Lasalle County.
Sylvan Dell Spring, Galewood, Cook County.
White Diamond, formerly Spouting Mineral Spring, South Elgin, Kane County.

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[a] Chemical Survey of the Waters of Illinois. Report for the years 1897-1902, by Arthur Williars Palmer. Published by the University, 1903, pp. 8-9.

[b] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

The aggregate sales of these 22 springs are given as 1,767,955 gallons, with a value of $89,565.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale. Bull. U. S. Geol. Survey No. 32, pp. 142–144.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 25–30

Water resources of Illinois, by Frank Leverett: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 695–849.

Wells of Illinois, by Frank Leverett: Mon. U. S. Geol. Survey, vol. 38, pp. 550–787.

Description of the Danville quadrangle, by M. R. Campbell and Frank Leverett: Geol. Atlas U. S., folio 67, U. S. Geol. Survey.

Description of the Chicago district, by W. C. Alden: Geol. Atlas U. S., folio 81, U. S. Geol. Survey.

Description of the Patoka quadrangle, by M. L. Fuller and F. G. Clapp: Geol. Atlas U. S., folio 105, U. S. Geol. Survey.

Geology of Illinois as related to its water supply, by Charles W. Rolfe: Report on Chemical Survey of the Waters of Illinois. University of Illinois, 1903, pp. 41–56.

INDIANA.

By Frank Leverett.

INTRODUCTORY STATEMENT.

This brief discussion of water conditions in Indiana, like that of Illinois, is restricted chiefly to the relative value of the several geologic formations as water bearers. A more detailed discussion of drainage systems, underground waters, mineral springs, and water supplies for cities and villages will be found in a paper[a] by the author which appears in the Eighteenth Annual Report of the United States Geological Survey (pp. 425–559) and a discussion of the wells of Indiana, taken up county by county, in Water Supply and Irrigation papers Nos. 21[b] and 26.[c] The geologic structure of Indiana has been discussed in part or as a whole in several of the reports of the State geological survey, but except the very excellent discussion of mineral waters in the Twenty-sixth and Twenty-seventh Annual Reports, the State reports contain little information concerning water supplies. A paper on the "Natural Gas Field of Indiana," by A. J. Phinney, in the Eleventh Annual Report of the United States Geological Survey (pp 509–742), presents many data concerning water supplies.

GEOLOGIC COLUMN.

The formations exposed in Indiana extend with but slight breaks from the Hudson River group to the Coal Measures. There is then a wide gap, the next formation being of Tertiary (?) age, after which another interval appears between the Tertiary (?) and the glacial formations. The table on page 259 gives the formations penetrated by the drill, beginning with the newest and extending to the oldest. It also includes the formations below the Hudson River group which have been reached by the drill.

[a] Water resources of Indiana and Ohio.
[b] Wells of northern Indiana.
[c] Wells of southern Indiana.

Generalized section of the rock formations of Indiana.

[Modified from section of A. J. Phinney in the Eleventh Annual Report of the U. S. Geological Survey, pp. 624-625.]

	Thickness.
	Feet.
Recent deposits, alluvium, peat, marl, etc	5–50
Wisconsin drift sheet (Pleistocene)	5–250
Loess, marl loess, white clay, etc. (Pleistocene)	5–50
Illinoian drift sheet (Pleistocene)	5–250
Kansan and pre-Kansan drift sheets (?) (Pleistocene)	(?)
Tertiary (?) deposits (age undetermined)	5–50
Upper Coal Measures (Carboniferous)	50–195
Middle Coal Measures (Carboniferous)	600–888
Lower Coal Measures and Conglomerate (Carboniferous)	60–210
Chester group (Carboniferous)	0–74
St. Louis group (Carboniferous)	0–330
Keokuk group (Carboniferous)	6–106
Knobstone and Waverly (Carboniferous)	42–532
Black shale (Devonian)	70–120
Brown shale (Devonian)	25–47
Hamilton limestone and shale (Devonian)	47
Upper Helderberg (Devonian)	5–65
Schoharie (?) (Devonian)	14–20
Lower Helderberg (Silurian)	25–230
Waterlime (Silurian)	65–150
Niagara group (Silurian)	52–480
Clinton group, limestone and shale (Silurian)	46
Medina (?) (Silurian)	60
Hudson River group (Ordovician)	260–860
Utica shale (Ordovician)	0–300
Trenton group (Ordovician)	486–525
St. Peter (Ordovician)	150–224
Lower Magnesian (Cambrian)	400±
Potsdam sandstone (Cambrian)	323+

PRINCIPAL WATER-BEARING FORMATIONS.

St. Peter sandstone.—The St. Peter sandstone, in the Indiana field, usually is a calcareous, loose-textured rock, saturated with salt water, containing more or less sulphate of magnesia and sulpureted hydrogen. It may, however, be potable in the extreme northwest part of the State.

Trenton limestone.—The porous portion of the Trenton limestone, except in parts of the State where it carries natural gas and oil, is also saturated with salt water, the water taking the place of the gas and oil as the latter become exhausted by pumping.

Hudson beds.—The Hudson group is a very poor water bearer, being composed largely of shale. It is used to a limited extent, however, at its outcrop in the southeastern part of the State to supply water for domestic use.

Clinton and Medina beds.—The Clinton and Medina are comparatively thin formations with very limited areas of outcrop, and are, as a rule, inferior water bearers.

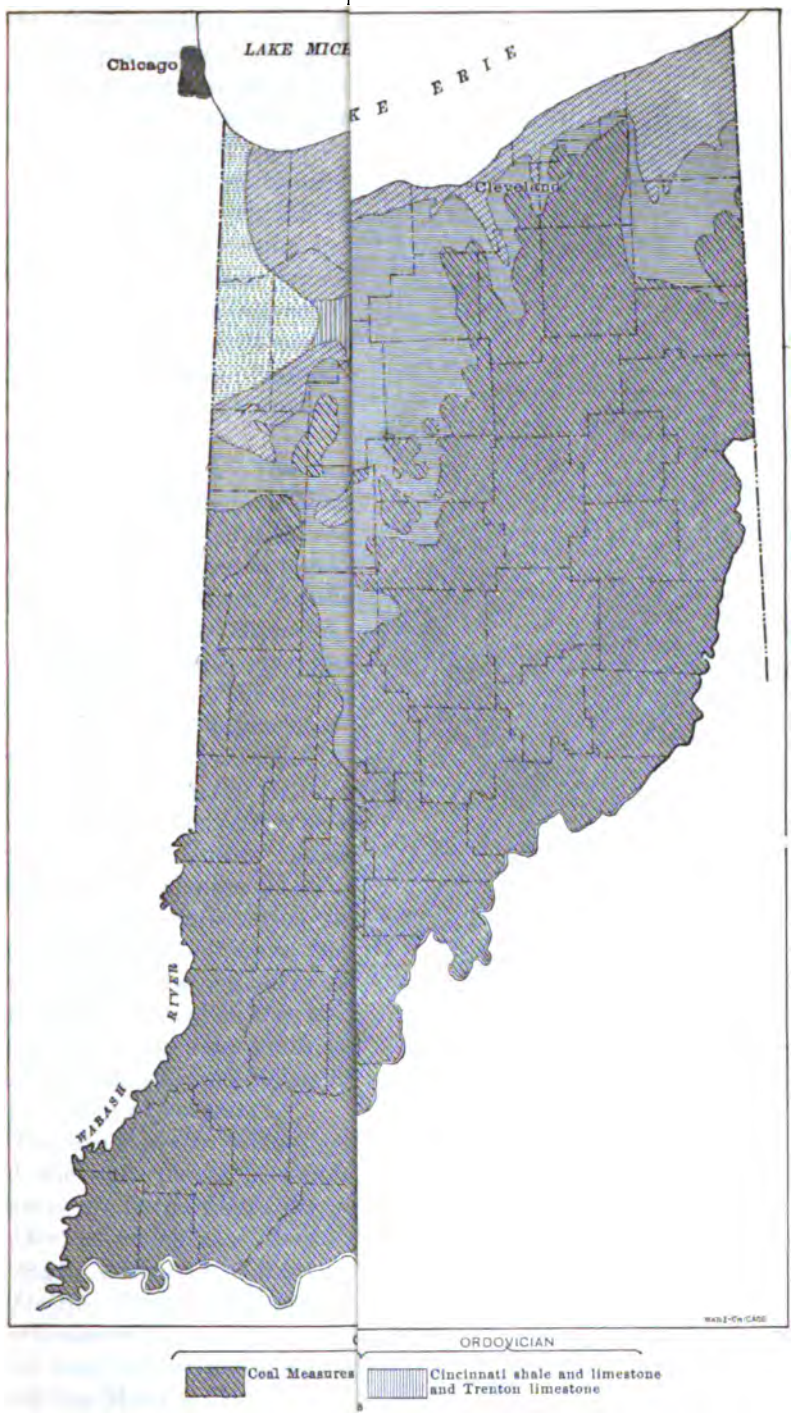
Niagara limestone.—The Niagara group consists largely of a limestone which, as in Illinois, contains a large amount of water, generally palatable and suitable for domestic use. In some cases, as in Illinois, the water is charged with sulphureted hydrogen produced through the decomposition of pyrite included in the limestone. This limestone furnishes probably the most abundant supply of water suitable for domestic use to be found in any single rock formation, since it is struck at moderate depth in much of the eastern part of the State. When it passes under the cover of later formations and sinks to considerable depths the water becomes brackish and is unsuitable for domestic use.

Waterlime and Lower Helderberg limestones.—The limestone formations above the Niagara to the base of the Devonian shale afford good supplies of water in the region of outcrop, water being generally struck in veins or fissures, as in the Niagara limestone. The outcrops are, however, comparatively few, since these formations are ordinarily buried under very heavy deposits of drift. Their value as water bearers is found chiefly along the Wabash Valley above Delphi and in the southern part of the State, where the drift is thin or wanting.

Devonian shale.—The Devonian shale which underlies heavy deposits of drift in the northern part of the State and also a narrow strip leading west of north from Ohio River at New Albany to the Tippecanoe near Monon is perhaps the poorest water-bearer in the State, but it is so generally deeply covered by water-bearing beds of drift that there is little need of penetrating it.

Waverly shale.—The Waverly shale, which is found on the north border of the State, like the Devonian shale, is a very poor water-bearer, and like it, too, is concealed deeply beneath water-bearing beds of drift.

Knobstone formation.—The Knobstone formation from the central part of the State southward constitutes the knobs or most hilly tracts of southern Indiana, and includes some sandstones as well as shales. It is covered by drift north from northern Brown County, and the drift-covered portion is not drawn upon for wells to any notable degree. The driftless portion of this formation is only sparsely settled and the residents depend to a large degree upon springs which issue from the sandstone beds along the valley slopes. The water is ordinarily fresh and much softer than that obtained from neighboring limestone formations.


Chicago
LAKE MICHIGAN
LAKE ERIE
Cleveland
WABASH RIVER
ORDOVICIAN
Coal Measures
Cincinnati shale and limestone and Trenton limestone

St. Louis limestone beds.—The St. Louis limestone belt occupies in its outcrop a width of about 20 miles, and extends from Ohio River in Harrison County, west of north through Washington, Orange, Lawrence, Monroe, Owen, Morgan, Putnam, and Montgomery counties to the borders of the Wabash Valley above Attica. It is unglaciated as far north as northern Monroe County, and furnishes the sole supply for the residents, with the exception of the rain water collected in cisterns. There are some localities in which the expense of sinking wells into the limestone far enough to strike water is so great that cistern water has come into use for drinking as well as for other domestic purposes. In the drift-covered portion of this limestone belt a large part of the wells are obtained without entering the limestone, though its several members appear to be good water bearers wherever penetrated.

Chester sandstone.—The sandstones which come in between the limestone group and the Coal Measures form a narrow strip running from Perry County, on Ohio River, west of north to the Wabash Valley at the vicinity of the great bend near Attica. The region between Ohio River and White River is either driftless or carries only a thin deposit of drift, and the sandstone supplies water at moderate depths and also is the source of many springs, usually of fresh water.

Coal Measures.—The Coal Measures of the southwestern part of Indiana are either unglaciated or covered to only a slight depth with drift, but in western Indiana they are so thickly covered that wells are either obtained in the drift or at the junction of the drift with the rock. Wells which have been sunk into the rock have in some cases struck "copperas water" at moderate depths, and salt water is usually encountered at depths of more than 200 feet. To obtain good water in this region exploration should be made by the drill until fresh water free from sulphates has been reached. Waters with objectionable properties which occur at higher levels can then be cased out, as is impracticable when the wells are dug. In some localities it seems necessary to use rain water collected in cisterns, the sulphates in the waters from the rock being so generally present that good wells are very difficult to obtain.

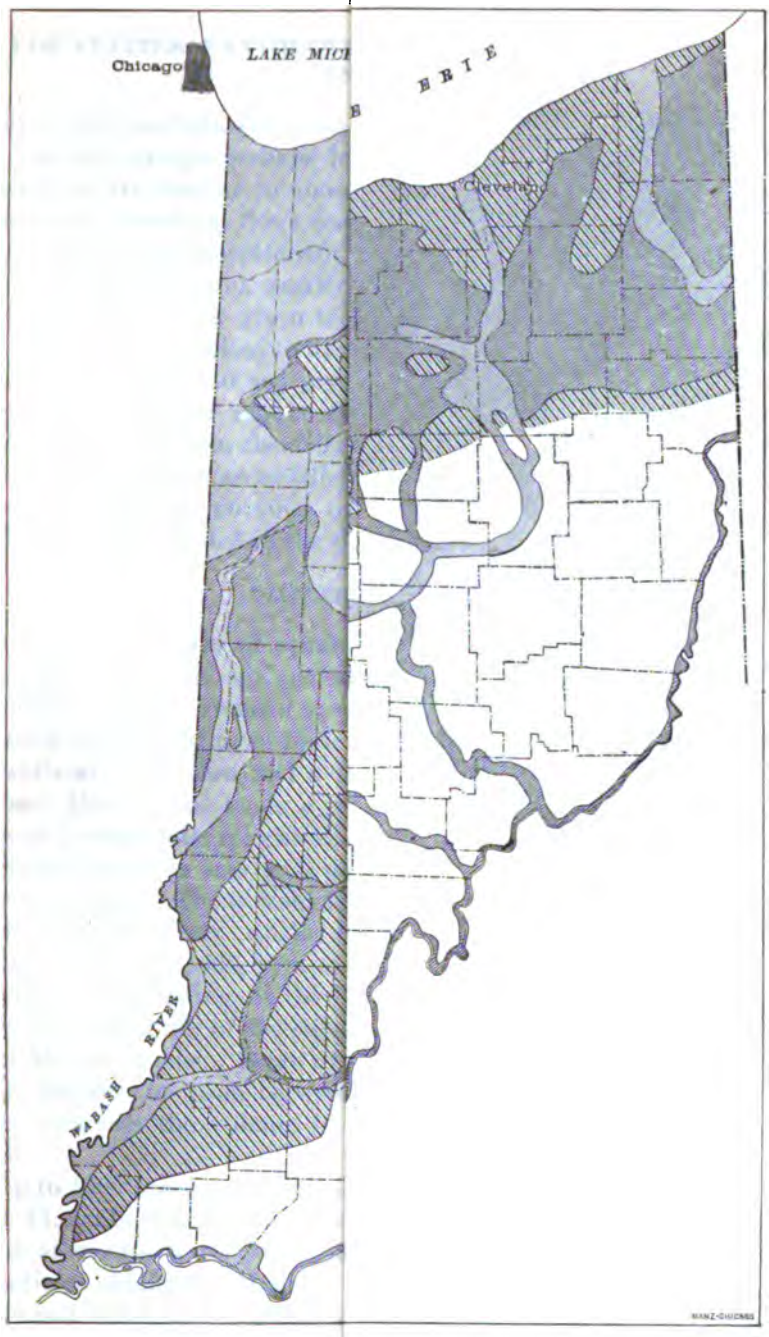
Tertiary deposits.—The Tertiary deposits are of very limited extent, and the only places in which they appear to be of value as water-bearers are found where the gravels have been redeposited in the Ohio Valley, in which case they sometimes yield springs of considerable strength, some of which are to be found below Rockport.

Drift.—The glacial deposits of Indiana extend to Ohio River, in the southeastern part of the State, but the drift border runs northward from near Jeffersonville to northern Brown County, and thence westward into Monroe County, passing a little north of Bloomington. The

course is then southwestward across Greene, Martin, Dubois, Pike, Gibson, and Posey counties to the mouth of the Wabash. From about the latitude of Indianapolis southward the thickness of the drift is very moderate, except along the line of pre-Glacial valleys, but in nearly all parts of the State north of this latitude there is a heavy deposit which in places reaches a thickness of 500 feet, and averages about 200 feet. The average thickness in the entire glaciated portion of the State is estimated to be about 130 feet. There are a few counties in the southeastern part, and small tracts in the southwestern, where the drift is composed very largely of compact clayey material, which is such a poor water-bearer that wells have been sunk into the rock formations. Elsewhere in the State it is the exception to find a well extending to the rock without encountering more or less water-bearing gravel and sand. In the areas of thickest drift the gravel and sand generally greatly preponderate over clayey material. The large amount of gravel and sand in the drift of this State seems due to the fact that there was a crowding or converging of ice lobes which entered the State from the great basins of Lake Michigan, Saginaw Bay, and Lake Erie, which would naturally produce a great amount of glacial drainage.

In the Illinois district, where the single ice lobe from the Lake Michigan basin was free to spread widely, the streams occupied only a small part of the glaciated area, and thus left wide strips in which there was very little movement of waters to carry away the clayey material. In Indiana as well as in Illinois there were oscillations of each of the several ice lobes, which have resulted in alternations of beds of various degrees of coarseness and permeability to water. In the final retreat of the ice an extensive but comparatively thin sheet of sand was deposited over the district between the Kankakee and Tippecanoe rivers in northwestern Indiana, but elsewhere in northern Indiana the surface capping is largely clay. The inferior quality of much of the water in the rock formations of Indiana is more than made good by the great abundance of excellent water in the drift, so that the State is, as a whole, highly favored in its water supply for all domestic uses.

The map of Indiana and Ohio, Pl. XVIII, shows not only the relation of the wells to the drift, but also the parts of the State in which the drift is of exceptional thickness. It should perhaps be stated that in the portion where the drift is but 25 to 75 feet thick wells are commonly obtained without entering the rock, and rock wells are nearly as rare as in the districts where there is more than 100 feet of drift.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LOCALITIES FAVORABLE FOR ARTESIAN WELLS IN INDIANA.

There are no extensive areas in this state where artesian wells may be obtained, except perhaps in the northwestern counties where the conditions are similar to those of the neighboring part of Illinois. Elsewhere occasional flows have been obtained in the valleys of the main streams or exceptionally low parts of interfluvial tracts. The deep borings were sunk usually for the purpose of obtaining oil or gas, little attention being given to the head attained by water. The data are therefore insufficient to warrant definite statements concerning the head to be expected at any given place or conclusions concerning the regularity or lack of regularity in the hydrostatic pressure.

Flowing wells from the drift have only been obtained in very small areas, which, like those of Illinois, are situated usually on the inner slopes of prominent moraines or in the valleys. Numerous notes may be found recorded in the papers by the author referred to above.

MINERAL WATERS.

Mineral waters are of common occurrence in Indiana as in other states, both springs and wells. Mr. W. S. Blatchley has made an extended study of such waters and has published a report treating of their character and uses.[1] Many springs are described and a large number of analyses are given. Mr. Hessler has made a report on the medicinal springs of Indiana mineral waters.[2]

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LOCALITIES FAVORABLE FOR ARTESIAN WELLS IN INDIANA.

There are no extensive areas in this State where artesian wells may be obtained, except perhaps in the northwestern counties where the conditions are similar to those of the neighboring part of Illinois. Elsewhere occasional flows have been obtained in the valleys of the main streams or exceptionally low parts of interfluvial tracts. The deep borings were sunk usually for the purpose of obtaining oil or gas, little attention being given to the head attained by water. The data are therefore insufficient to warrant definite statements concerning the head to be expected at any given place or conclusions concerning the regularity or lack of regularity in the hydrostatic pressure.

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Up to 1886 few deep wells had been drilled, but since that date more than 14,000 bore holes have been sunk. Some of these flowed, and in many others the water rose nearly to the surface. Large supplies are sometimes obtained. Much of the water is highly mineralized and of medicinal value, and wells have been developed in many instances into important resorts.

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[a] Indiana Dept. Geol. Nat. Resources, Twenty-sixth and Twenty-seventh Ann. Repts., pp. 11-158.
[b] Ibid., pp. 159-224.

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[a] Indiana Dept. Geol. Nat. Resources, Twenty-sixth and Twenty-seventh Ann. Repts., pp. 11-158.
[b] Ibid., pp. 159-224.

The water is to a considerable extent used at the individual wells or springs, but in 1902 shipments from 16 springs amounted to 273,380 gallons, with a value of $236,501. The average price per gallon is the highest in the country.[a] Following is a list of the springs reporting:

Attica Lithia Springs, Attica, Fountain County.
Elliott Springs, Willow Valley, Martin County.
Emerald Spring, Indiana Mineral Springs, Warren County.
French Lick Springs, French Lick, Orange County.
Greenwood Mineral Well, Greenwood, Johnson County.
Kickapoo Magnetic Spring, Kickapoo, Warren County.
King's Mineral Spring, Muddyfork, near Dallas, Clark County.
Laxine Spring, Mount Moriah, Brown County.
Lodi Artesian Well, Silverwood, Fountain County.
Magnetic Mineral Spring, Terre Haute, Vigo County.
Mudlavia, formerly Indiana Mineral Springs, Mudlavia, Warren County.
Mudlavia Artesian Sulphur Spring, Mudlavia, Warren County.
Porter Mineral Springs, near Porter's Depot, Porter County.
Shelbyville Lithia Spring, Shelbyville, Shelby County.
West Baden Springs, West Baden, Orange County.
Winona Lithia Spring, Winona Lake, Kosciusko County.

PRINCIPAL PUBLICATIONS.

Water resources of Indiana and Ohio, by Frank Leverett: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4.

Wells of northern Indiana, by Frank Leverett: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 21, 1899.

Wells of southern Indiana, by Frank Leverett: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 26, 1899.

Description of the Danville quadrangle, by M. R. Campbell and Frank Leverett: Geol. Atlas U. S., folio 67, U. S. Geol. Survey.

Description of the Chicago district, by W. C. Alden: Geol. Atlas U. S., folio 81, U. S. Geol. Survey.

Mineral waters of Indiana, by W. S. Blatchley: Indiana Geol. Survey, vol. 26, pp. 11–158.

The medicinal properties of Indiana mineral waters, by Robert Hessler: Indiana Geol. Surv., vol. 26, pp. 159–226.

Description of the Ditney quadrangle, by M. L. Fuller and G. H. Ashley: Geol. Atlas U. S., folio 84, U. S. Geol. Survey.

Description of the Patoka quadrangle, by M. L. Fuller and F. G. Clapp: Geol. Atlas U. S., folio 105, U. S. Geol. Survey.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

OHIO.

By Frank Leverett.

INTRODUCTORY STATEMENT.

A somewhat detailed discussion of drainage systems, mineral springs, and water supply for cities and villages will be found in a paper by the author which appears in the Eighteenth Annual Report of the United States Geological Survey.[a] The drainage features, both present and pre-Glacial, and the glacial formations in their relation to water supplies are treated at some length by the author in Monograph XLI of this survey. The rock waters and flowing wells of Ohio are discussed by Edward Orton in a paper in the Nineteenth Annual Report of the United States Geological Survey. The paper covers the subject of the relative value of the several geologic formations as water-bearers. In Ohio the State board of health is required by law to approve all public water supplies when introduced, and their reports may be consulted for analyses made in accordance with this law. A report published in 1898 contains an exceptionally full discussion of water supplies, and includes the paper by Orton, referred to above.

GEOLOGIC COLUMN.

[Modified from paper of Edward Orton in Nineteenth Annual Report of the U. S. Geological Survey.]

Formation.	Thickness.
	Feet.
Recent deposits, alluvium, peat, marl, etc.	5–50
Wisconsin drift sheet (Pleistocene)	0–300
The loess or white clay (Pleistocene)	3–15
Illinoian drift sheet (Pleistocene)	10–250
Upper Barren Coal Measures (Carboniferous)	500±
Upper Productive Coal Measures (Carboniferous)	200±
Lower Barren Coal Measures (Carboniferous)	500±
Lower Productive Coal Measures (Carboniferous)	250±
Conglomerate Coal Measures (Carboniferous)	250±

[a] Water resources of Indiana and Ohio, Eighteenth Ann. Rept., pt. 4, pp. 425–559.

Formation.	Thickness.
	Feet.
Logan group (Eocarboniferous)	0–300
Cuyahoga shale (Eocarboniferous)	150–450
Berea shale and grit (Carboniferous)	25–150
Bedford shale and sandstone (Carboniferous)	50–150
Ohio shale, etc. (Devonian)	250–2,500
Corniferous limestone (Devonian)	25–100
Onondaga limestone (Silurian)	20–600
Niagara group, limestone and shale (Silurian)	150–350
Clinton limestone (Silurian)	20–150
Medina shale (Silurian)	25–150
Hudson River group, shales and limestones (Ordovician)	300–800
Utica shale (Ordovician)	0–300
Trenton group (Ordovician)	300–600

CHARACTERISTICS OF WATERS OF DIFFERENT DEPTHS.

The following general principles have been stated by Orton in the report above mentioned:

1. The subterranean waters from a comparatively shallow depth carry, as a rule, dissolved carbonates. Lime and magnesia are the leading bases, but potassium and sodium also occur in small quantities. Iron is unfailingly present, and often in notable quantity. These wells are common sources of potable supply.

2. Water from a greater depth holds dissolved chlorides as well. Chloride of sodium is by far the most common, but chlorides of magnesium and calcium are also often added. The presence of chlorides is seldom shown in water at less than 100 feet in depth, and where found they are confined to a few formations of the Ohio column. It is very rare that the drill descends to 300 feet without encountering saline water or water too highly mineralized with other elements to be acceptable for the highest uses. Aside from that of a few wells in glacial drift no water of the State is known that comes from a depth greater than 500 feet and still remains free enough from mineral solutions to warrant its use as potable.

3. Sulphates are generally found in the deeper waters, but are also found in the shallower waters. The most common compound is calcium sulphate; but sodium sulphate is not infrequent.

4. Sulphides also, particularly sulphureted hydrogen, though often rising to the surface in so-called sulphur springs, are especially characteristic of waters found in limestones, and nearly all of the water of the great Ohio shale system is characterized in this way. Sulphides pass into sulphates very promptly and by reactions easily understood.

RELATIVE VALUE OF DIFFERENT ROCK FORMATIONS AS WATER-BEARERS.

Of the large number of formations present in Ohio, as indicated in the section above, Orton considers only the following to be important water-bearers: Trenton limestone, Clinton limestone, Niagara limestone, Onondaga limestone, Corniferous limestone, Logan sandstone,

Berea grit, Carboniferous conglomerates, and certain sandstone beds of the Coal Measures.

Trenton limestone.—The waters of the Trenton limestone are all highly mineralized and have a strong, bitter, or saline taste; they are also charged heavily with sulphureted hydrogen.

Clinton limestone.—The Clinton limestone affords a large number of springs along its outcrop in Preble, Montgomery, Warren, Greene, and Clinton counties. This limestone when under a deep cover of later formations carries water too highly mineralized for a potable supply. It is therefore utililized for domestic purposes only along the line of outcrop.

Niagara limestone.—The Niagara limestone contributes its most important supplies of water where it immediately underlies the glacial drift in a few counties in the western part and a narrow strip leading from there southward to Ohio River in Adams County. Orton refers to the effect of atmospheric agencies in enlarging the joints of the limestone and establishing underground reservoirs and channels for waters which sink into this formation from the overlying drift deposits.

Onondaga limestone.—The Onondaga limestone is considered by far the most important source of underground water. The great area of its outcrop in the west-central and northern portions of the State, as well as the thickness of the formation and its soluble character, furnish the basis for this estimate. A considerable number of cities and villages depend upon this limestone for water supply.

Corniferous limestone.—The Corniferous limestone is considered of small importance as a source of water because of its comparatively small area of outcrop. Several flowing wells in the city of Columbus have, however, been obtained from it, and there are numerous springs issuing from it along the Scioto Valley.

Logan sandstone.—The Logan sandstone is a water-bearing stratum wherever found at the surface. It outcrops prominently in Richland, Ashland, and Wayne counties. Artesian wells have been obtained from it at several points in Wayne County, and the water supply of Orrville is from this source.

Berea grit.—The Berea grit is also a good water bearer along the line of its outcrop and often affords supplies when covered by the Cuyahoga shale to moderate depths. Such is the case at the village of New London.

Coal Measures.—The Conglomerate Coal Measures contain a white and pebbly sand of great purity—the Sharon conglomerate—which in its outcrop in northeastern Ohio affords excellent wells. The city of Massillon now derives its supply from this source. Cuyahoga Falls also stands on this conglomerate and the wells of the village are largely obtained in it.

The water supply of the Coal Measures proper is rather inferior. Excellent water can be secured almost everywhere, but it is considered doubtful if the supply will be adequate for the growing towns that are located within the boundaries of this formation. It is probable that the streams of the region will need to be drawn upon for public water supply.

Drift.—The glacial deposits furnish by far the largest amount of potable water to be obtained within the State. These deposits cover nearly three-fourths of the State, the southeastern portion only being unglaciated. The valley gravels have been carried down the main valleys of the driftless portion of the State and hold much of the water of the valley drainage at convenient depth for wells; the quality of water is generally excellent. The Illinoian drift sheet extends beyond the Wisconsin only in a few counties in the central and southwestern parts of the State. This drift sheet is composed largely of clayey material except along the line of pre-Glacial valleys, where there is found to be a large filling of sand or coarser water-bearing material. Within the limits of the Wisconsin drift the moraines are usually composed in large part of gravelly or sandy material, but in some cases wells have to be sunk to considerable depth to strike strong water veins. On the plains between the moraines beds of sand and gravel are usually found sandwiched between beds of clay or till at convenient depth. Throughout the greater part of the drift-covered portion of the State good wells are obtained at depths of 50 feet or less, and there are only a few localities in which it is necessary to sink to depths of 100 feet or more. There are, however, localities in which strong supplies are obtained at moderate depth, and yet borings have been sunk 100 feet in order to obtain flowing wells.

Much of the surface portion of the drift is a clayey material which protects wells obtained in underlying deposits from surface contamination. Even the areas covered by great glacial lakes in the northwest part of the State have usually a clayey soil, the principal exception being a belt of sand north of Maumee River in Fulton and Lucas counties. The relation of wells to drift formations may be seen by reference to the map, Pl. XVIII.

LOCALITIES FAVORABLE FOR ARTESIAN WELLS.

Artesian wells from rock formations are comparatively rare, although the water is usually under considerable hydrostatic pressure. Orton calls attention to strong flowing wells near Orrville obtained from the Logan conglomerate or sandstone and to flows at Massillon from the Sharon conglomerate and to a few others at points scattered over the State. There appears to be no extensive areas of artesian water open to development in the State from any of the rock formations. The glacial deposits are a much more productive field for exploration.

Flowing wells have been obtained without entering the rock in a belt on the inner slope of the great morainic system that runs from southeastern Michigan across northwestern Ohio into Indiana. Hundreds of wells have already been obtained in Williams, Defiance, and Fulton counties. The wells range from shallow fountains, differing but little from boiling springs, in which pipes are driven only 10 to 20 feet into the ground up to borings nearly 200 feet in depth. In much of that region the thickness of the drift is 150 to 200 feet or more. Flowing wells are also found along the line of deep pre-Glacial channels in Allen, Auglaize, and Mercer counties at depths ranging from 100 feet or less up to 350 feet, and wells have in some cases been continued to depths of more than 400 feet without striking the rock. Records of many of these wells are presented in the report by Orton, mentioned above. There are many other places in Ohio where flowing wells are found in small areas of a square mile or less to which attention has been directed by the author in Monograph XLI. These wells are usually on the iceward slope of moraines, and the region of intake is probably restricted largely to the moraine adjacent to them. They are of various depths, from 20 feet or less up to 100 feet or more. Probably further exploration with deep borings would enlarge such flowing well areas or increase the number of areas in which flows are obtained, for in a great many districts the occurrence of abundant water at moderate depths has freed the residents from the necessity of drilling deeply to test the chances for artesian waters.

MINERAL SPRINGS.

Both the drift and the rocks of Ohio yield a considerable number of springs. The springs of the drift vary with the nature of the local materials, but are generally hard and may carry much iron. The rock waters of the Coal Measures are frequently salt or chalybeate, while those of the limestones are generally hard. Many of the springs have been developed as resorts, while others place their water on the market for medicinal or other purposes. Twenty such springs reported sales in 1902, the amount of which aggregated 1,948,840 gallons, with a value of $172,746.[a] The springs reporting are as follows:

Alba Spring, Rockfort, Cuyahoga County.
Arcadian Springs, Mineral Springs, Adams County.
Buckeye Lithia Spring, near Martins Ferry, Belmont County.
Concord Crystal Spring, Concord, Lake County.
Crum Mineral Spring, Austintown, Mahoning County
Crystal Rock Spring, near Sandusky, Erie County.
Deerfield Mineral Springs, Deerfield, Portage County.
Fargo Mineral Springs, Ashtabula, Ashtabula County.
Green Spring Artesian Mineral Well, Green Springs, Sandusky County.
Knisely Mineral Springs, Bucyrus, Crawford County.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

La Fountaine Springs, Fountain Park, Champaign County.
Magnetic Magnesia Well, Canton, Stark County.
Oakridge Spring, Greensprings, Sandusky County.
Painesville Mineral Spring, Painesville, Lake County.
Puritas Spring, Rockport, Cuyahoga County.
Purtlebaugh Mineral Spring, Urbana, Champaign County.
Rex Ferro-Lithia Springs, New Richmond, Clermont County.
Ripley Brom-Lithia Springs, Ripley, Brown County.
Talewanda Mineral Springs, near College Corner, Preble County.
Wheeler Mineral Springs, Youngstown, Mahoning County.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 130–134.

Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, pp. 21–28.

Water resources of Indiana and Ohio, by Frank Leverett: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4.

Rock waters of Ohio, by Edward Orton: Nineteenth Ann. Rept. U. S. Geol. Survey, pt 4.

WEST VIRGINIA.

By M. L. Fuller.

West Virginia has through a large portion of its area a rugged topography. It is mountainous only in the eastern part, where it borders the Appalachian ridges, but even in the western portion it is so cut by streams with intervening narrow ridges that there is little even moderately level land, except the narrow strips along some of the streams. The conditions are therefore very favorable for springs, which, with spring-fed streams, constitute the main source of water supply over a large part of the State.

Topographically and geologically it may be divided into two distinct belts: (1) The Appalachian Mountain belt, including the Shenandoah Valley, and (2) the Cumberland Plateau.

APPALACHIAN MOUNTAIN BELT.

This term is here used, as elsewhere in the report, in its broad sense, and includes the area of folded rocks lying between the crystalline rocks of the Piedmont Plateau of Virginia on the east, and the area of gently folded to nearly flat rocks of the Allegheny Plateau on the west. The belt is crossed by the "handle" of West Virginia, and a narrow strip along its whole eastern boundary is included. The rocks are mainly Cambrian, Silurian, and Devonian in age, although a few small areas of Carboniferous rocks are included, especially near the western borders of the belt. The rocks include quartzites, sandstones, shales, and limestones, the latter occurring principally in the Shenandoah Valley at the extreme eastern extension of the panhandle, and as a strip along the western base of the mountain belt. The former belongs to the Cambro-Silurian rocks, and the latter to the Carboniferous.

Except in the Shenandoah and other smaller valleys, this area is thinly inhabited, and small springs constitute the main source of water supply. In the limestone valleys wells are sometimes resorted to, but reliance in the main is placed on cisterns, because of the uncertainty of the occurrence of water in the limestone. A few large springs issue from the limestones, from the more porous sandstones,

and more rarely from the shales. The waters are often mineralized and of medicinal value, and a considerable number of springs have been developed as resorts. Some of the waters are thermal.

CUMBERLAND PLATEAU.

The greater portion of the area of the State falls within what may be termed the Cumberland Plateau, which may be considered as entering the State from Kentucky on the south. The plateau does not present an even surface, but has been cut by streams until only narrow-crested ridges remain to represent the original level. In a broad way the slope is to the northwest, away from the mountains, the altitude varying from 3,500 feet at the western base of the mountains to less than 1,000 feet near the Ohio River. The river bottoms are sunk several hundred feet below the upland level. At the northern boundary of the State the Cumberland Plateau merges with the Allegheny Plateau of Pennsylvania.

The rocks belong mainly to the coal-bearing division of the Carboniferous, and are either inclined at a low angle or gently folded. Because of the numerous springs few attempts have been made to obtain water by deep borings, but the wells drilled for oil and gas frequently obtain abundant water, some of which flows in the synclines or under other favorable conditions.

The stratified deposits along Ohio River and some of the other large streams yield good water to shallow wells, but their area is limited.

MINERAL SPRINGS.

In 1902 nine springs reported sales of mineral water. The total output is stated to be 92,310 gallons and to have a value of $25,343.[a] Several of the springs are also developed as resorts.

Capon Springs, Capon Springs, Hampshire County.
Greenbrier Alum Spring, near Lewisburg, Greenbrier County.
Greenbrier White Sulphur Springs, White Sulphur Station, Greenbrier County.
Magnesia Spring, No. 2, near Wheeling, Ohio County.
Manacea Irondale Spring, near Independence, Preston County.
Pence Spring, Pence Springs, Summers County.
Red Sulphur Springs, Red Sulphur Springs, Monroe County.
Triplet Well, Calf Creek, Grant District, Pleasants County.
Webster Springs, Webster Springs, Webster County.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 69–73.
Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, pp. 61–64.

[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904 p. 996.

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Water-Supply and Irrigation Paper No. 115 Series N, Water Power, 10

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

RIVER SURVEYS AND PROFILES MADE DURING 1903

ARRANGED BY

W. CARVEL HALL AND JOHN C. HOYT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

ERRATA.

[Water-Supply Paper No. 115, United States Geological Survey.]

Page 11. Fig. 1 should have had the title "Profile of Catawba River from Marion to Connelly Springs, N. C.," and been placed at page 13.

Page 14. Pl. II should have had the title "Profile of Tallulah River below Blalock, Ga.," and been placed at page 18.

Page 19. Fig. 2 should have had the title "Profile of Tugaloo River below Tallulah Falls, Ga.," and been placed at page 23.

Page 24. Fig. 3 should have had the title "Profile of Savannah River from Andersonville, S. C., to Lisbon, Ga.," and been placed at 29.

Page 30. Pl. III should have had the title "Profile of South and Ocmulgee rivers from Constitution to Macon, Ga.," and been placed at page 46.

Page 47. Fig. 6 should have had the title "Profile of Alcovy River below Dabney's bridge, Georgia," and been placed at page 56.

Page 56. Fig. 8 should have had the title "Profile of upper Chattahoochee River from Nacoochee, Ga., to junction with Chestatee River," and been placed at page 61.

Page 62. Fig. 10 should have had the title "Profile of lower Chattahoochee River from West Point to Columbus, Ga.," and been placed at page 71.

Page 73. Fig. 12 should have had the title "Profile of Chestatee River below Willow, Ga.," and been placed at page 77.

Page 76. Pl. IV should have had the title "Profile of Chippewa River from Reeds Landing, Minnesota, to Flambeau, Wis.," and been placed at page 98.

Page 103. Fig. 18 should have had the title "Profile of Buffalo River from Flatwoods to Lobelville, Tenn.," and been placed at page 11.

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., July 23, 1904.

SIR: I have the honor to transmit herewith a paper entitled "River Surveys and Profiles Made in 1903," which has been arranged by W. Carvel Hall and John C. Hoyt.

This paper contains the results of the cooperative river surveys carried on during 1903 between the topographic and hydrographic branches.

There is a large demand for the data herein presented by engineers and others interested in power development. I therefore recommend that this manuscript be published as a Water-Supply and Irrigation Paper.

Very respectfully, F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

RIVER SURVEYS AND PROFILES OF 1903.

Arranged by W. C. HALL and J. C. HOYT.

INTRODUCTION.

In order to determine the location of the undeveloped water powers on the various rivers in the United States the United States Geological Survey has from time to time made surveys and profiles of the more important of the rivers on which possible power sites were known to be located. The object of these surveys is to point out localities where power may be developed.

In the determination of the river profiles the general plan of survey adopted was as follows:

The elevations were based upon reliable heights derived from primary or precise levels of the United States Geological Survey. On this datum, with few exceptions, lines of flying levels were carried up the bank of each stream and bench marks were established at intervals of about 1 mile, usually on nails on tree roots. The elevations of the surface of the water at the head and foot of each shoal, rapid, or fall were noted. These levels, with few exceptions, have been tied at both ends. In the case of Broad River primary levels were used instead of flying levels, and regulation bronze tablets left at intervals of 6 miles.

The horizontal control of the survey was by plane table oriented by compass, while the distance was always obtained by means of stadia measurements. To further insure the accuracy of the work, the stadia rod was so divided that one division on it equaled one division of the scale used in plotting.

The field sheets were plotted on the scale of 1 : 22,500, with the exception of the surveys of the Tallulah and Tugaloo rivers, which were on the scale of 1 : 45,000. Several different runs of river were plotted on the same plane-table sheet, the ends of the different sections being so marked that there would be no difficulty in joining them and making one continuous map.

On these sheets were shown the outlines of the river banks, the islands, the positions of rapids, shoals, falls, and existing dams, the

crossings of all ferries and roads, and as much of the culture of the river bottom as could be obtained without leaving the immediate neighborhood of the river. The river banks were contoured carefully and the adjacent river bottoms sketched, all with an interval of 10 feet. On these field sheets are marked in their proper positions the elevations of the various bench marks left, as are also the elevations of the water surfaces wherever obtained.

For each river surveyed, first are given a brief description, a list of the elevations, and a condensed profile of the portion of the river surveyed.

The elevations as given in the original notebooks have been adjusted in accordance with the various primary heights tied to, and the figures herein given are the ones obtained from this adjustment.

On file in the Washington office are the original topographic sheets and profiles on the scale of 1 inch to a mile horizontal and 1 inch to 100 feet vertical.

ACKNOWLEDGMENTS.

In the collection of these data and their preparation for publication special acknowledgment is due to the levelmen and others who carried on the surveys. Acknowledgment is due, also, to Messrs. B. M. Hall and M. R. Hall for suggestions, and to Messrs. C. B. Kendall and D. H. Baldwin, who adjusted the various lines of levels, under the supervision of Mr. S. S. Gannett, geographer.

BUFFALO RIVER FROM FLATWOODS TO LOBELVILLE, TENN.

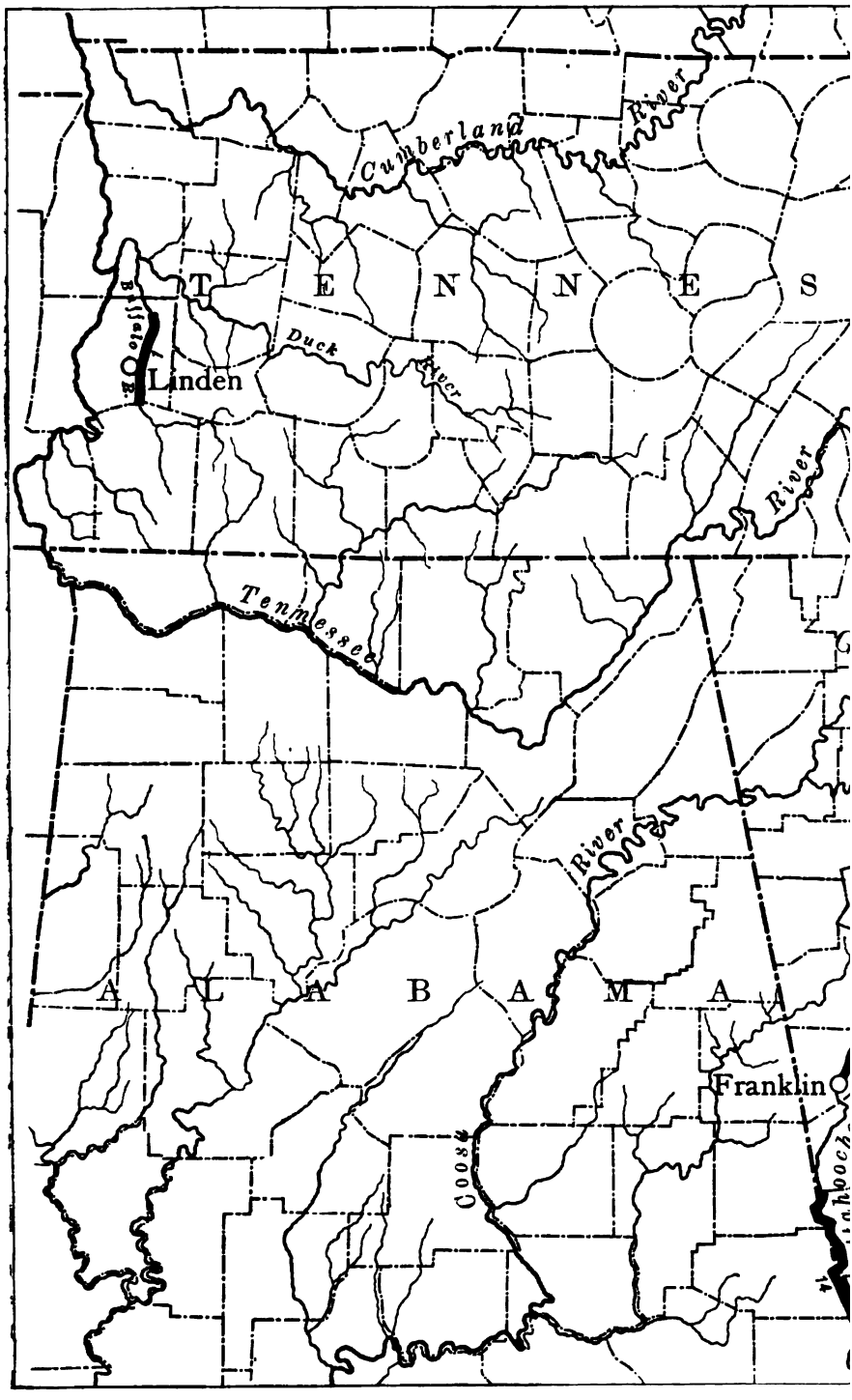
A line of flying levels was run on Buffalo River, Tennessee, from the mouth of Little Opossum Creek, near Flatwoods, to Standing Rock Ford, about 3 miles north of Lobelville—a distance of 47 miles. The plane-table survey was on the scale of 1: 22,500. During the course of the work 28 bench marks on tree roots were marked and 39 water-surface elevations were recorded.

The total fall of that stretch of the river is 109 feet, and is so evenly distributed that there seems to be no power site of any value. There are now two crude dams, one near Linden and the other near Lobelville, supplying power for small gristmills, but at neither place do the conditions warrant the construction of more substantial dams.

The soil near the river is fertile and well adapted to the cultivation of corn, hay, and peanuts.

The elevations in the following list are based upon an assumed elevation of 537.25 feet for the water surface at the mouth of Little Opossum Creek as interpolated from contours sketched on the Mannie sheet. The assumed elevation is probably within 20 feet of correct datum.

U. S. GEOLOGICAL SURVEY



MAP SHOWING LOCATION OF SURV

The leveling was done October 4 to 31, 1903, under the direction of Oscar Jones, topographer, by Ralph Hutchins, levelman.

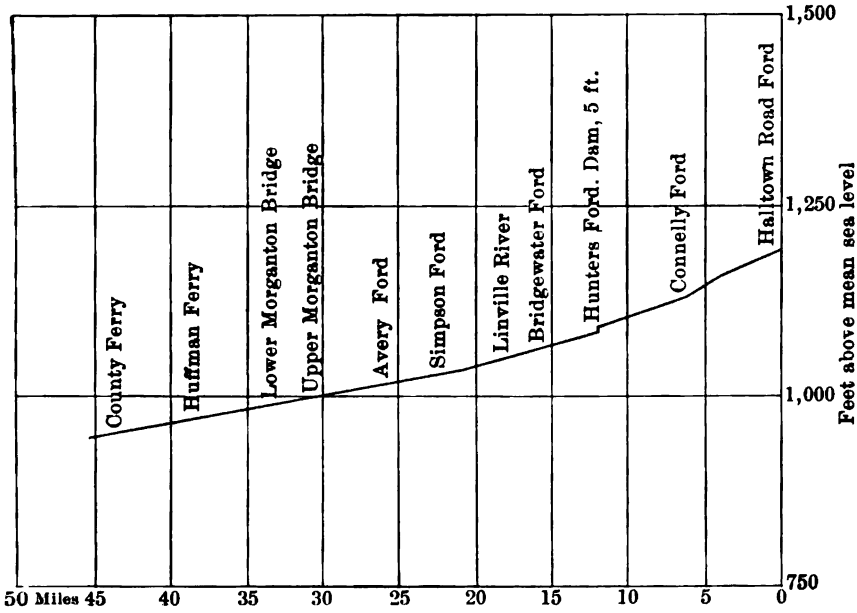


FIG. 1.—Profile of Buffalo River from Flatwoods to Lobelville, Tenn.

Elevations on Buffalo River, Tennessee, from Little Opossum Creek to Standing Rock Ford.

Distance in miles.		Elevation in feet.
0.0	Little Opossum Creek, mouth of; east side of river at ford, hackberry tree, nail in root of	537.25
.0	Surface of water	533
.3	East side of river at ford, nail in root of elm tree	532.26
.6	Ford, east side of, dead sycamore tree, nail in root of	531.59
1.0	Ford, 125 feet north of; east side of river, nail in root of sycamore tree	532.32
1.2	Surface of water	528
2.1	Ford, south side of river, nail in root of sycamore tree	529.06
2.2	600 feet north of ford, surface of water	525
4.1	Sinking Creek, east side of river, maple tree, nail in root of	524.90
4.1	Sinking Creek, mouth of, surface of water	520
6.3	Ford, 275 feet north of, north bank of river, east side of highway, at angle, nail in root of sycamore tree	521.16
6.2	Ford, 650 feet west of; surface of water	512
8.9	50 feet from river, south side of; sycamore tree, nail in root of	510.01
8.9	Surface of water	503
10.6	Ford, east bank of river, sycamore tree, nail in root of	500.70
10.8	Hurricane Creek, mouth of; surface of water	498
11.9	Hurricane Creek, 1.1 miles from; 50 feet east of ford, nail in root of beech tree	504.17

Elevations on Buffalo River, Tennessee, from Little Opossum Creek to Standing Rock Ford—Continued.

Distance in miles.		Elevation in feet.
11.9	Surface of water	494
13.2	At ford, east bank of river, nail in root of willow tree	489.53
13.2	Surface of water	487
15.2	At ford, south bank of river, nail in root of maple tree	484.23
15.2	Ford, 800 feet west of; surface of water	482
15.5	Ford, south bank of river, nail in root of sycamore tree	485.15
16.6	Ford, east bank of river, nail in root of sycamore tree	482.29
16.8	County bridge, west abutment, bolt in base of girder	499.45
17.3	Ford, east bank of, nail in root of sycamore tree	483.03
17.3	Surface of water	477
19.9	Coon Creek Ford, east bank of river, nail in base of willow tree	476.42
19.9	Ford, 350 feet north of, surface of water	471
21.3	Ford, 106 feet west of; west bank of river, nail in base of willow tree	470.04
21.3	Ford, surface of water	467
22.3	Ford, east bank of river, screw in base of sycamore tree	469.70
22.3	Ford, surface of water	465
22.6	Brush creek, east bank of river, nail in root of sycamore tree	467.29
22.6	Surface of water	465
23.7	Above dam, surface of water	464
23.7	Below dam, surface of water	459
24.2	Ford, west bank of river, top of large rock	459.32
24.2	Ford, 600 feet below, surface of water	457
26.1	Ford, west bank of river, top of large rock	454.16
26.1	Surface of water	452
26.6	Beardstown, east bank of river, at ford, nail in root of sycamore tree	454.24
26.6	650 feet below ford, surface of water	451
28.1	Ford, west bank of river, nail in root of sycamore tree	452.90
29.7	Ford, east bank of river, nail in root of hackberry tree	449.51
30.3	Ford, south bank of river, road, south side, nail in root of sycamore tree	445.47
30.3	Ford, 650 feet below, surface of water	441
31.9	Above dam, surface of water	441
31.9	Below dam, surface of water	435
31.9	Ford, south bank of river, road, west side, nail in root of sycamore tree	438.32
34.3	Ford, east bank of river, nail in base of sycamore sapling	434.02
34.3	Surface of water	431
35.4	Dodson Ford, east bank, top of rock	430.51
36.4	Hester Ford, surface of water	426.59
40.9	Logan Ford, south bank, west side of road, nail in base of willow tree	419.08
41.2	Standing Rock Ford, south bank, nail in root of maple tree	420.61

CATAWBA RIVER FROM MARION, N. C., TO CONNELLY SPRINGS, N. C.

Catawba River was surveyed from the Halltown road crossing, near Marion, N. C., down the river to the mouth of Johnsons Mill Creek, near Connelly Springs, N. C.—a distance of 45 miles. A line of flying levels was run in connection with the plane-table stadia traverse, which was on the scale of 1:22,500, based on a permanent bench mark of the United States Geological Survey at Marion, N. C. This flying line is connected with a precise line along the Southern Railway, run by the Geological Survey in 1896, at Bridgewater, Glen Alpine, Morganton, and Connelly Springs, at each of which points there is a permanent bench mark. There were only three temporary bench marks set along the river, but there were 160 water-surface elevations recorded, all of which were adjusted to the mean reading on the gage established at the upper bridge near Morganton. The work was done in July, August, and September, 1903, by R. C. Howard and S. A. Obenshain, under the direction of W. C. Hall, topographer.

In the stretch of river surveyed there is a total fall of 243 feet. At present there is only one crude dam—at John River Road Ford, where there is a fall of 4 feet, supplying power to operate Hunter's gristmill. There is a dam site near Connelly Ford. The combined fall of two shoals about half a mile apart is 12.3 feet and a long, rocky island in the lower part of the shoal would somewhat facilitate the construction of a dam. At this point the river is about 200 feet wide, with rocky cliffs on both banks. The river bottom is very fertile, the principal crops being corn and hay.

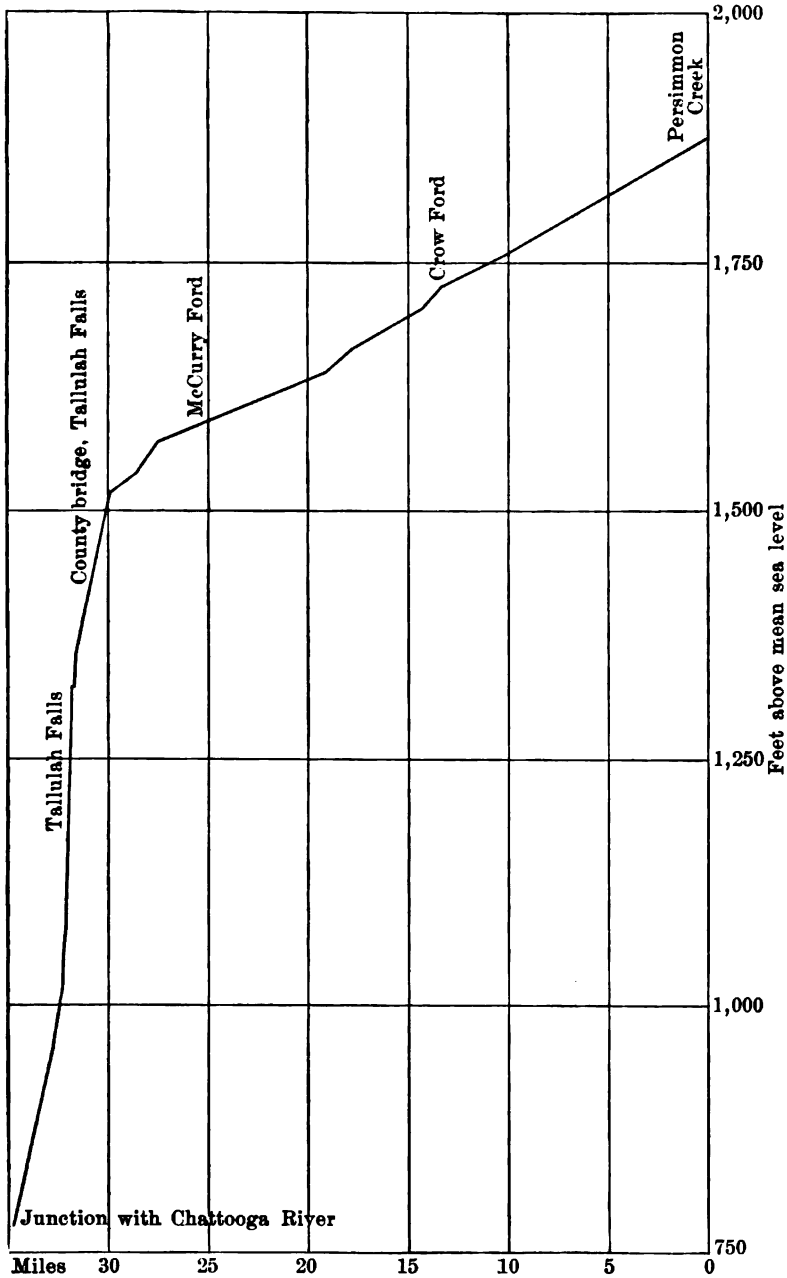
Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.

Distance in miles.		Elevation in feet
0.0	Halltown Road Ford, head of island, head of shoals, surface of water	[a]1,189
.1	Foot of shoals, surface of water	1,187
.2	Head of shoals, surface of water	1,187
.2	Foot of shoals, surface of water	1,184
.5	Head of shoals, surface of water	1,184
.7	Foot of shoals, surface of water	1,179
1.1	Mouth of North Fork, 0.5 mile above, head of shoals, surface of water	1,179
1.1	Foot of shoals, surface of water	1,177
1.3	Head of shoals, surface of water	1,177
1.3	Foot of shoals, surface of water	1,175
1.7	Head of shoals, surface of water	1,174
1.8	Foot of shoals, surface of water	1,172
2.1	Head of shoals, surface of water	1,170
2.3	Foot of shoals, surface of water	1,167

[a] Adjusted to bench mark at Marion; McDowell County court-house; west face, at south end of portico, bronze tablet marked "1438"; elevation, 1,436.857 feet.

Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.—Cont'd.

Distance in miles.		Elevation in feet.
2.4	Head of shoals, surface of water	1,166
3.2	Foot of shoals, surface of water	1,157
3.4	Head of shoals, surface of water	1,156
3.4	Foot of shoals, surface of water	1,154
4	Head of shoals, surface of water	1,153
4.2	North bank of island, foot of shoals, surface of water	1,146
4.4	Head of island, head of shoals, surface of water	1,146
4.4	Foot of island, foot of shoals, surface of water	1,141
4.7	Head of shoals, surface of water	1,140
4.7	Foot of shoals, surface of water	1,137
4.8	Head of shoals, surface of water	1,137
4.8	Foot of shoals, surface of water	1,134
5.1	Head of shoals, surface of water	1,134
5.1	Foot of shoals, surface of water	1,133
5.3	Head of shoals, surface of water	1,133
5.3	Foot of shoals, surface of water	1,131
5.4	Head of shoals, surface of water	1,131
5.4	Foot of shoals, surface of water	1,130
5.7	Connelly Ford, head of shoals, surface of water	1,130
5.8	Foot of shoals, surface of water	1,127
6	Head of shoals, surface of water	1,126
6	Foot of shoals, surface of water	1,126
6.1	Head of shoals, surface of water	1,125
6.1	Small island in shoals, foot of shoals, surface of water	1,124
6.6	Between large islands, head of shoals, surface of water	1,124
6.7	Foot of islands, foot of shoals, surface of water	1,122
6.9	At head of broad flood channel, head of shoals, surface of water	1,122
7	Foot of shoals, surface of water	1,119
7.3	At foot of broad channel, head of shoals, surface of water	1,119
7.3	Foot of shoals, surface of water	1,116
7.5	Head of shoals, surface of water	1,116
7.5	Foot of shoals, surface of water	1,115
7.8	Head of shoals, surface of water	1,115
7.8	Foot of shoals, surface of water	1,114
8.2	Head of shoals, surface of water	1,113
8.5	Foot of shoals, surface of water	1,108
8.5	Head of shoals, surface of water	1,108
8.7	Foot of shoals, surface of water	1,105
9.2	John River Road, head of shoals, surface of water	1,103
9.2	Foot of shoals, surface of water	1,102
9.8	Just below ford, head of shoals, surface of water	1,101
9.8	Foot of shoals, surface of water	1,099



PROFILE OF CATAWBA RIVER FROM MARION TO CONNELLY SPRINGS, N. C.

Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.—Cont'd.

Distance in miles.		Elevation in feet.
10	Head of island, head of shoals, surface of water	1,099
10.2	Foot of shoals, surface of water	1,094
10.8	Head of shoals at head of island, surface of water	1,094
10.9	Foot of island, foot of shoals, surface of water	1,092
11.1	Head of shoals, surface of water	1,092
11.1	Foot of shoals, surface of water	1,089
11.6	Just above dam, surface of water	1,089
11.6	Below ford, foot of shoals, surface of water	1,084
12	Head of shoals, surface of water	1,083
12	Foot of shoals, surface of water	1,079
12.4	Head of shoals, surface of water	1,079
12.4	Foot of shoals, surface of water	1,079
13	Head of shoals, surface of water	1,078
13.1	Foot of shoals, surface of water	1,075
13.3	Head of shoals, surface of water	1,075
13.3	Foot of shoals, surface of water	1,074
13.5	Below head of island, head of shoals, surface of water	1,074
13.7	Foot of two islands, foot of shoals, surface of water	1,070
13.9	Head of shoals, surface of water	1,070
13.9	Foot of shoals, surface of water	1,070
14.4	Head of shoals, surface of water	1,069
14.4	Foot of shoals, surface of water	1,069
14.5	Bridgewater, in front of station, top of north rail	[a]1,095.7
14.5	Head of shoals, surface of water	1,068
14.6	Foot of shoals, surface of water	1,068
15	Head of shoals, surface of water	1,067
15	Foot of shoals, surface of water	1,066
15.1	Just above head of shoals, surface of water	1,066
15.2	Head of shoals, surface of water	1,065
15.2	Foot of shoals, surface of water	1,062
15.4	Head of shoals, surface of water	1,062
15.5	Foot of shoals, surface of water	1,062
15.8	Head of shoals, surface of water	1,061
15.9	Foot of shoals, surface of water	1,061
16.4	Head of shoals, surface of water	1,058
16.8	Foot of shoals, surface of water	1,056
17	Head of shoals, surface of water	1,054
17.2	Foot of shoals, surface of water	1,054
18	Just above head of upper island, head of shoals, surface of water	1,051
18.1	Between island and south bank of river, foot of shoals, surface of water	1,049

[a] Bridgewater, 0.4 mile east of; bridge seat at west end of Muddy Creek Bridge, 2.75 feet south of south rail, copper bolt marked "U. S. G. S., 1091;" elevation, 1,089.549 feet.

Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.—Cont'd.

Distance in miles.		Elevation in feet.
18.2	Mouth of Linville River, below ford, at head of island and south bank, head of shoals, surface of water	1,048
18.4	Between island and south bank, foot of shoals, surface of water	1,046
18.7	Head of small island, head of shoals, surface of water	1,045
18.7	Center of island, foot of shoals, surface of water	1,045
18.9	Head of two small islands, head of shoals, surface of water	1,045
19.1	Foot of shoals, surface of water	1,040
19.6	Long narrow island along north bank, head of short shoal, surface of water	1,039
19.8	Head of shoals, surface of water	1,038
19.8	Foot of shoals, surface of water	1,037
20.1	Above ford, head of shoals, surface of water	1,036
20.3	Head of shoals, surface of water	1,035
20.4	Foot of shoals, surface of water	1,033
20.9	Head of shoals, surface of water	1,032
20.9	Foot of shoals, surface of water	1,031
21.3	Head of shoals, surface of water	1,031
21.3	Foot of shoals, surface of water	1,030
21.5	Head of shoals, surface of water	1,030
21.7	Head of large island, head of shoals, surface of water	1,030
22	250 feet below foot of large island, foot of shoals, surface of water	1,026
22.4	Ford, head of shoals, surface of water	1,026
22.5	Foot of shoals, surface of water	1,025
23.4	Head of shoals, surface of water	1,024
23.7	Head of shoals, surface of water	1,023
23.7	Foot of shoals, surface of water	1,022
24	Head of shoals, surface of water	1,022
24.3	Foot of shoals, surface of water	1,016
25	Avery Ford, 50 feet above, head of shoals, surface of water	[a] 1,015
25	Foot of shoals, surface of water	1,013
25.4	Head of shoals, surface of water	1,013
25.4	Foot of shoals, surface of water	1,012
26.6	Between long island and north bank of river, head of shoals, surface of water	1,009
26.6	Foot of shoals, surface of water	1,007
27.2	Surface of water	1,006
28.1	Head of shoals, surface of water	1,004
28.2	Head of long narrow island, foot of shoals, surface of water	1,003
29	Greenlea Ford, head of shoals, surface of water	1,001
29.1	Foot of shoals, surface of water	1,001

[a] Circuit from White Ford to Avery Ford is adjusted to Glen Alpine, 73.2 feet north of north rail of main track, southeast corner of brick basement of Hennessee & Co.'s store, bronze tablet marked "1215;" elevation, 1,213.944 feet.

Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.—Cont'd.

Distance in miles.		Elevation in feet.
29.4	Between island and mouth, head of shoals, surface of water	1,000
29.6	Foot of island, foot of shoals	998
29.9	Head of shoals, surface of water	998
29.9	Foot of shoals, surface of water	997
30.2	Upper Morganton Bridge, head of shoals under, surface of water	[a] 996
31.7	Fleming Ford, head of islands at, head of shoals, surface of water	992
32	Foot of shoals, surface of water	988
33	Lower Morganton Bridge, under, surface of water	986
33.5	Head of shoals, surface of water	986
34.2	Foot of shoals, surface of water	977
34.4	Head of shoals, surface of water	976
34.8	Below island at mouth of creek on south bank, foot of shoals, surface of water	974
35.5	Mouth of John River, surface of water	972
37.1	Head of shoals, surface of water	969
37.9	Foot of shoals, surface of water	963
38.5	Huffman Ferry, north bank, west side of road, nail in post	974.2
	Huffman Ferry, at east corner of Huffman's house, nail in root of tree at	1,011.75
38.5	Surface of water	961
38.7	Head of shoals, surface of water	959
40.7	At mouth of creek on south, head of shoals, surface of water	957
40.7	Foot of shoals, surface of water	956
41.2	Head of large island, head of shoals, surface of water	955
41.2	Between island and north bank of river, foot of shoals, surface of water	955
41.4	Foot of island, head of shoals, surface of water	955
41.4	Foot of shoals, surface of water	955
41.6	Lovelady Ford, at head of small island between large island and south bank, head of shoals, surface of water	954
41.8	Lovelady Ford, north bank of river, surface of water	953
41.9	Foot of large island at foot of shoals, surface of water	951
43.6	County Ferry, 200 feet south of; west side of road, nail in box alder	968.8
43.6	Surface of water	948
43.8	Head of shoals, surface of water	947
43.8	Foot of shoals, surface of water	947
44.5	Head of shoals, surface of water	947
44.5	Foot of shoals, surface of water	[b] 946

[a] Upper Morganton Bridge line adjusted to Morganton, Burke County court-house, extreme northwest corner of north portico, bronze tablet marked "1182;" elevation, 1,180.774 feet.

[b] Connelly Springs, 142.4 feet north of north rail of main track, James Hudson's brick store, south front, near east corner, bronze tablet marked "1193;" elevation, 1,191.762 feet.

Johnson Mill Creek flows into Catawba 1.6 miles below County Ferry, south side of river.

NOTE.—Water-surface elevations adjusted to mean gage reading 1.8 feet at Upper Morganton Bridge Elevation of 1.8-footmark, 996.3 feet.

TALLULAH RIVER BELOW BLALOCK, GA.

Tallulah River rises in Habersham and Rabun counties, Ga., flows in a southeasterly direction, and joins Chattooga River a little below Tallulah Falls, thus forming Tugaloo River. During August, 1903, this river was surveyed between Tallulah Falls, Ga., and the mouth of Persimmon Creek, near Blalock, Ga. The distance between these points is about 33 miles, and there is a fall of 451 feet. The survey consisted of a line of primary levels based upon the United States Geological Survey bench mark at Tallulah Falls, and a plane-table survey of the course of the river. The field sheets were plotted on a scale of 1:22,500, 30 bench marks were established, and 69 water-surface elevations obtained.

Tallulah River is a typical mountain stream and is subject to sudden freshets. As the Chattooga is of the same character the Tugaloo is a dangerous stream, a rise of 1.6 feet per hour for three consecutive hours being recorded on March 23, 1903, at the Southern Railway bridge near Toccoa, Ga. On this occasion the river rose 15.2 feet in eighteen hours.

Tallulah River crosses the fall line at Tallulah Falls, Ga. In this vicinity is some of the most picturesque and rugged scenery in the Southern States. In 3 miles the river drops from 1,415 to 755 feet above sea level, or a distance of 660 feet. The principal falls, in the order in which they occur, are L'eau D'or, 28 feet; Tempesta, 76 feet; Hurricane, 89 feet; Oceana, 41 feet; Bridal Veil, 17 feet—all in a distance less than three-fourths of a mile. On either bank are precipitous cliffs, rising in some places 500 feet sheer. The gorge continues to the Tugaloo, with the exception of one place about one-half mile long, where it opens up and forms what is known as the Old Valley farm. On either side the country is covered with woods, but not a great deal of merchantable timber appears to be available.

In 2 miles, above Tallulah Falls, the river has a fall of 110 feet. At the head of this fall the bottom widens into a valley which appears to be an excellent basin for storing water. Three and one-fourth miles farther upstream at an unnamed shoal with a 12-foot fall, there is a fair site for a dam. The bottom is rocky, and there are steep hills on either side.

Five miles farther upstream is a shoal with a 25-foot fall, steep hills on either side, and hard rock bottom. Just above Denton Ford is a 23-foot shoal about three-fourths of a mile long where there is a splendid site for a dam.

The fall in the lower Tallulah below the falls is about 250 feet. A large portion of this fall can be used for power without interfering with the resort at Tallulah Falls. By installing an electrical plant at the upper end of Old Valley farm a good power could be obtained.

The elevations in the following list are based upon the elevation of a bronze tablet in rock 70 feet east of the public road and 20 feet south of Tallulah Falls, station marked "1569 Atlanta." This elevation is accepted as 1,568.302 feet above mean sea level in accord with the 1903 adjustment of the precise-level net. The line is corrected to accord with primary work at mouth of river and at Burton.

The leveling was done in 1903, under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

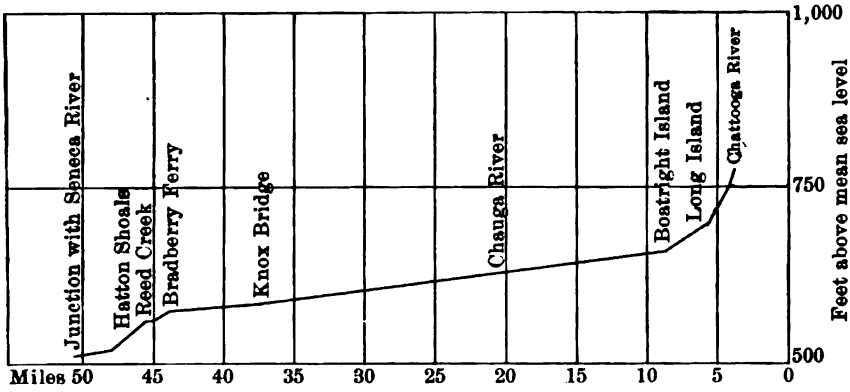


FIG. 2.—Profile of Tallulah River below Blalock, Ga.

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.

Distance.		Elevation in feet
0.0	Junction of Chattooga and Tallulah rivers, surface of water	754
.0	100 feet north of junction rivers, edge of river, point on rock	761.29
.0	200 feet north of junction rivers, west side of Tugaloo River, gum tree, nail in root of	762.65
.2	Chattooga River, 500 feet north of, west side of Tallulah River, nail in root of oak stump	769.46
.3	Surface of water	767
.4	Mouth of small stream, surface of water	782
.6	150 feet west of river	799.86
.9	Surface of water	818
1.3	Surface of water	848
1.6	Surface of water	878
1.7	Surface of water	893
1.8	Surface of water	911
2	Foot of rapids, surface of water	935
2.1	Middle of rapids, surface of water	944
2.2	Head of rapids, surface of water	947
2.2	Foot of rapids, surface of water	954
2.25	Surface of water	964

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.—Cont'd

Distance in miles.		Elevation in feet.
2.3	Foot of small falls, surface of water	981
2.35	Foot of rapids, surface of water	987
2.38	300 feet below bend, head of rapids, surface of water	980
2.4	Surface of water	997
2.5	Surface of water	1,008
2.6	Bridal Veil Falls, foot of, surface of water	1,022
2.6	Head of falls, surface of water	1,039
2.65	Surface of water	1,057
2.8	Oceana Falls, foot of, surface of water	1,074
2.85	Head of falls, surface of water	1,115
3.1	Hurricane Falls, foot of, surface of water	1,140
3.1	Head of Hurricane Falls, surface of water	1,229
	Tempesta Falls, foot of, surface of water	1,246
3.1	Tempesta Falls, head of, surface of water	1,322
3.2	L'eau d'or Falls, foot of, surface of water	1,322
3.2	L'eau d'or Falls, head of, surface of water	1,350
3.3	Surface of water	1,379
3.4	Surface of water	1,396
3.6	Clayton Road iron highway bridge, surface of water	1,414
	Tallulah Falls station, 70 feet east of public road, 20 feet south of station, in rock, bronze tablet marked "1569 Atlanta"	1,568.302
3.6	Tallulah Falls, 0.5 mile northeast of; at forks of road, 50 feet south of bridge over river	1,457.92
3.6	Clayton Road iron highway bridge, 0.5 mile north of Tallulah Falls, floor of	1,441.87
	Surface of water	1,419
	Opposite stone pier railroad bridge, surface of water	1,439
	Surface of water	1,449
	On rock, surface of water	1,459
4.9	Foot of falls, surface of water	1,486
4.9	Top of falls, surface of water	1,492
5.1	Surface of water	1,509
5.5	Head of island, surface of water	1,530
5.6	20 feet west of Tallulah Falls Railroad, point on top of rock	1,538.21
5.6	Surface of water	1,529
6	Surface of water	1,538
6.5	Surface of water	1,553
6.6	Surface of water	1,559
7.3	150 feet east of river, in cornfield, dead apple tree, nail in root of	1,579.23
7.3	Surface of water	1,569
8.4	Surface of water	1,573

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.—Cont'd.

Distance in miles.		Elevation in feet.
8.6	Surface of water	1,578
8.7	65 feet north of river, in cornfield, walnut tree, nail in root of	1,589.25
8.7	Surface of water	1,578
9.6	Tiger Creek, on point of land between river and creek, burnt poplar tree, nail in side of	1,590.30
9.6	Surface of water	1,584
9.9	Surface of water	1,589
10	5 feet west of river, in footpath, point on sharp rock	1,595.59
10.2	Surface of water	1,592
10.4	Surface of water	1,596
10.5	10 feet west of river, nail in root of beech tree	1,601.32
10.6	Surface of water	1,600
10.9	Surface of water	1,603
11.8	Crane Ford, 150 feet west of, apple tree, nail in root of	1,620.33
11.8	Surface of water	1,607
12.1	Surface of water	1,610
13.3	Dockens Ford, 12 feet west of river, nail in side of dead tree	1,623.06
13.3	Surface of water	1,615
13.8	Ellord Ford, 150 feet east of, at bend of, poplar tree, nail in side of	1,634.36
13.8	Surface of water	1,621
14.4	Surface of water	1,626
14.5	Surface of water	1,628
14.6	Eden Church, 150 feet west of, 150 feet east of river, nail in root of large red-oak tree	1,649.41
15.6	Taylor Shoals, 10 feet west of river, middle of, point on large flat rock	1,644.90
15.6	Surface of water	1,641
16.2	Surface of water	1,648
16.5	Surface of water	1,657
16.6	Surface of water	1,657
17.7	James Smith boat landing, 2 feet west of river, nail in stump	1,670.53
18.4	Fall Creek, mouth of, surface of water	1,669
18.6	Jones Ford, 6 feet south of river, slanting persimmon tree, nail in side of	1,677.33
18.6	Surface of water	1,674.6
19.2	Flat Creek, mouth of, surface of water	1,681
20.6	Surface of water	1,687
20.9	Cliff Creek, mouth of, surface of water	1,690
21.4	Surface of water	1,697
21.5	Denton Ford, 10 feet west of river, nail in root of pine tree	1,703.61
21.5	Surface of water	1,701
21.8	Mouth of small stream, surface of water	1,703
21.9	Seal Creek, mouth of, foot of double shoals, surface of water	1,704

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.—Cont'd.

Distance in miles.		Elevation in feet.
22	Surface of water	1,707
22.3	Middle of shoals, surface of water	1,714
22.6	Crow Ford, 100 feet south of, 10 feet south of river, twin hemlock tree, nail in root of	1,725.93
22.6	Surface of water	1,724
22.7	Scarecrow Creek, mouth of, surface of water	1,727
24	George Creek, mouth of, surface of water	1,737
24.5	Bridge Creek, mouth of, surface of water	1,738
25	In shoals, surface of water	1,747
25.1	—— Ford, surface of water	1,749
25.1	At above ford, south edge of river, point on rock	1,750.29
25.6	Rocky Ford, 10 feet south of, dead hemlock tree, nail in root of	1,758.47
25.6	Surface of water	1,756
25.9	Surface of water	1,757
26.2	Kenny Creek, mouth of, surface of water	1,760
26.3	Fuller Ford, surface of water	1,760
26.4	Fuller Ford, 500 feet northwest of, point on rock	1,762.62
27	Surface of water	1,767
27.3	Cannon Ford, 75 feet southwest of, nail in root of white oak	1,781.97
27.3	Surface of water	1,769
28.2	—— Ford, west side of, nail in root of red gum tree	1,777.87
28.2	Surface of water	1,774
28.5	Wildcat Creek, 50 feet southwest of, west side of road, point on rock	1,783.19
28.5	Surface of water	1,776
29.3	Surface of water	1,785
29.5	Surface of water	1,787
29.6	Dicks Creek, surface of water	1,789
30.1	Burton, 12 feet southwest of bridge, nail in root of maple tree	1,794.96
30.1	Floor of bridge	1,806.4
30.1	Surface of water	1,790
30.1	High-water mark	1,804
30.2	Burton, 1,000 feet above bridge, 15 feet east of river, 10 feet west of road, bronze tablet marked "——"	1,795.140
32.1	12 feet west of ford, nail in side of ash tree	1,819.04
32.1	Surface of water	1,813
32.4	Surface of water	1,819
32.7	Murford, 100 feet southwest of, nail in west side of white-oak tree	1,838.05
32.7	Surface of water	1,824
33	Rocky Ford, surface of water	1,829
33.1	Shallow Ford, 500 feet southeast of, in road, point on rock	1,841.48
33.2	Surface of water	1,835.

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.—Cont'd.

Distance in miles.		Elevation in feet.
33.6	Deep Ford, 30 feet south of, nail in side of sycamore tree	1,842.39
33.6	Surface of water	1,839
34.3	Popcorn Creek, mouth of, surface of water	1,849
35	Deep Ford, 3 feet east of, nail in side of beech tree	1,862.03
35.8	Persimmon Creek, 75 feet east of river, 30 feet south of creek, nail in side of hickory tree	1,881.67

TUGALOO RIVER BELOW TALLULAH FALLS, GA.

Tugaloo River, which flows in a southeasterly direction between Georgia and South Carolina, is a continuation of Savannah River, and extends from the mouth of Seneca River to the mouth of Chattooga River. The bed of the stream is in Georgia. The survey of this river covered a distance of 50½ miles. It connected with the survey of Savannah River at Andersonville, and extended past the mouth of the Chattooga along the Tallulah as far as Tallulah Falls. The primary levels were based upon the United States Geological Survey bench mark at Parkesville, Ga. Nine bench-mark tablets and 64 temporary bench marks were established, and 98 water-surface elevations were obtained. The plane-table sheets were plotted on a scale of 1:22,500 for that portion of the survey above the mouth of the Chattooga; from that point to Owens Shoals the scale was 1:45,000; between Owens Shoals and Andersonville it was 1:22,500.

From the head of the Tugaloo to a point about one mile above the mouth of Panther Creek the banks are very steep, but are not so marked as along the Tallulah, except in some places where there is a cliff on one side. Below the point above mentioned the bottom is from one-fourth to three-fourths mile wide in most places, the soil being very fertile and in a high state of cultivation. Cotton is the main crop, with corn next, wheat, rye, sugar cane, etc., combined making but a small percentage of the yield. The timber is very scattered.

The elevations in the following list are based on an aluminum tablet marked "1050 M. C." at Washington street entrance to the State capitol at Atlanta, the elevation of which is now accepted as 1,049.546 feet above mean sea level. The initial point upon which these levels depend is a bronze tablet at north side of east entrance at court-house at Clarksville, Ga., marked "1373 Atlanta," the elevation of which is accepted as 1,371.991 feet above mean sea level, in accord with the 1903 adjustment of the precise-level net.

The leveling was done in 1903 under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

All permanent bench marks are marked with the letters "Atlanta" in addition to the figures of elevation.

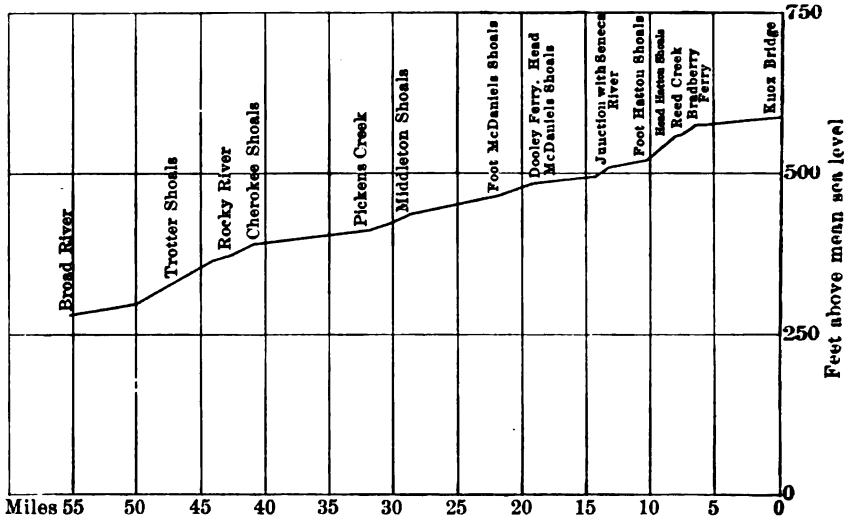


FIG. 3.—Profile of Tugaloo River below Tallulah Falls, Ga.

Elevations from Clarksville, via Turnerville, to Tallulah Falls, Ga.

	Elevation in feet
Clarksville, Habersham County court-house, north side of east entrance, bronze tablet marked "1373 Atlanta"	1,371.991
Clarksville, 0.7 mile southeast of, west side of road, nail in root of oak tree	1,436.353
Clarksville, 2 miles east of, south of track, nail in root of old stump	1,444
Clarksville, 1.5 miles east of station, dogwood tree, nail in root of	1,457.576
Clarksville, 2.5 miles east of, at railroad crossing, south of track, oak tree, nail in root of	1,419.40
Clarksville, 4.5 miles east of, oak stump, nail in root of	1,440.16
Clarksville, 6 miles east of, nail in root of oak tree	1,513.52
Clarksville, 7.5 miles east of, nail in root of oak tree	1,475.66
Turnerville station, 30 feet north of, nail in root of cottonwood tree	1,542.98
Turnerville, 1.9 miles northeast of, south of track, nail in root of oak tree	1,590.48
Turnerville, 3.2 miles northeast of station, nail in stump of gum tree	1,588.65
Turnerville, 4 miles northeast of, at road crossing east of track, nail in root of persimmon tree	1,612.33
Tallulah Lodge, 40 feet east of track, nail in side of hickory tree	1,605.84
Tallulah Falls station, 20 feet south of, 70 feet east of public road, rock, bronze tablet marked "1569 Atlanta"	1,568.302
Tallulah Falls, 0.5 mile north of east of, at forks of road, 50 feet south of bridge over river	1,457.92

Elevation from point 2 miles south of Tallulah Falls south down Tugaloo and Savannah rivers to mouth of Broad River, Lisbon, Ga.

	Elevation in feet.
Turnerville, 3.2 miles east of station, nail in stump of gum tree	1,588.65
Turnerville, 4.3 miles east of, nail in root of oak tree	1,504.20
Turnerville, 4.4 miles east of, nail in root of pine tree	1,386.10
Turnerville, 5.1 miles east of, south of road, point on rock	979.72

Elevations on Tugaloo River below Tallulah Falls.

Distance in miles.		Elevation in feet.
0.0	Junction of Tallulah and Chattooga rivers, 200 feet northwest of, gum tree, west side of Tallulah River, nail in root of gum tree	762.65
.0	Junction of rivers, 100 feet northwest of; edge of river, point on rock	761.29
.0	Junction of Tallulah and Chattooga rivers, water surface	754
.0	Tugaloo River, head of, pine tree, nail in root of	728.86
.7	Island, head of, surface of water	723
.8	Surface of water	711
2	Surface of water	698
2	West side of river, point on rock	698.79
2.1	Surface of water	690
2.4	Surface of water	686
2.8	Hickory tree, nail in root of	690.51
2.8	Surface of water	684
2.9	Surface of water	681
3.1	Small stream, mouth of, surface of water	674
4.4	Panther Creek, mouth of, surface of water	669
4.4	Panther Creek, 600 feet south of mouth and 50 feet west of river, west edge of public road, in large rock, bronze tablet marked "715 Atlanta"	713.793
5.3	Surface of water	667
5.4	Deaton Ford, surface of water	666
5.4	Small bridge, surface of water	664
5.4	Walnut tree, nail in root of	676.45
6.3	Surface of water	659
6.4	Small creek, South Carolina side, mouth of, surface of water	655
7.4	Walnut tree, 100 feet west of river, nail in root of	664.87
7.5	Small boat landing, surface of water	652
8	Big John Creek, mouth of, surface of water	650
8.9	Prather's bridge, 100 feet northwest of river and old bridge, cottonwood tree, nail in side of	659.02
8.9	Surface of water	648
9.9	James Prather homestead, middle step front entrance, bronze tablet marked "728 Atlanta"	726.873

Elevations on Tugaloo River below Tallulah Falls—Continued.

Distance in miles.		Elevation in feet.
10.5	Stream, mouth of, surface of water	646
11.5	Surface of water	644
11.5	Apple tree, 600 feet west of river, nail in root of	657.40
13	Stream, mouth of, surface of water	642
13	Gum tree, 10 feet west of river, nail in root of	658.51
13.8	Gum tree, west edge of river, nail in root of	651.33
13.8	Toccoa Creek, mouth of, surface of water	641
13.9	Jarrett Bridge, surface of water (during flood Mar. 21, 1903)	642.5
15.4	Water oak tree, 4 feet east of river, nail in root of	642.50
15.4	Walnut tree, 50 feet west of railroad bridge, nail in root of	660.52
15.4	Railroad bridge crossing Tugaloo River, west abutment, bronze tablet marked "666 Atlanta"	665.467
15.4	Stream, mouth of, surface of water	640
16.4	Stream, mouth of, surface of water	639
16.5	Sycamore tree, 50 feet south of river, nail in root of	641.09
16.5	Stream, mouth of, surface of water	637
17.5	50 feet east of river, birch tree, nail in root of	646.91
18	Surface of water	636
18	200 feet east of county road, 100 feet west of river, walnut tree, nail in root of	648.60
19	Saw mill, mouth of stream opposite, surface of water	632
19.1	Walnut tree, nail in root of	647.65
20.1	Stream, mouth of, surface of water	630
21.3	Swamp bush, 3 feet northwest of river, nail in top of	634.60
21.7	Rock Creek, 10 feet south of, walnut tree, nail in root of	640.35
21.7	Surface of water	624
22	Jenkins Ferry, 400 feet northwest of, 200 feet west of river, walnut tree, nail in root of	638.10
22	W. J. Perkins homestead, north side of house, in chimney, 2 feet above ground, bronze tablet marked "732 Atlanta"	[a] 730.754
22	Surface of water	624
22	High water	638
22.3	Stream, mouth of, surface of water	622
22.4	Walnut tree, nail in stump	635.56
22.6	Walnut tree, 40 feet west of river, nail in root of	634.32
23.2	Birch tree, on edge of small stream, nail in root of	629.55
24.5	Surface of water	618
24.5	Small tree, 4 feet west of river, nail in root of	619.47
25.1	Surface of water	616
25.5	Pine tree, 50 feet west of river, nail in root of	625.12
25.7	Surface of water	614

[a] The above is on a single spur line.

Elevations on Tugaloo River below Tallulah Falls—Continued.

Distance in miles.		Elevation in feet.
26.1	Old stump, 41 feet west of river, nail in	615.42
26.3	Head of Shelor Shoals, surface of water	610
27.6	Walnut tree, 10 feet north of river, nail in root of	614.54
27.6	Surface of water	607
27.9	Surface of water	605
28.1	Large creek, mouth of, surface of water	604
29.1	Pine tree, 5 feet northeast of river, nail in top of	623.27
29.3	Shelor Ferry, water oak tree, 10 feet northeast of river, nail in root of	606.46
29.3	Surface of water	600
29.3	Shelor Ferry, 0.3 mile southwest of; 100 feet northwest of I. E. Martin's house, 10 feet north of road, in large rock, bronze tablet marked "630 Atlanta"	628.875
30.1	Stream, mouth of, surface of water	599
30.3	Sycamore tree, 10 feet north of river, nail in root of	601.17
30.3	Mouth of stream, near bend in river, surface of water	597
30.4	Water oak stump, 10 feet north of river, nail in root of	598.10
30.4	Surface of water	595
31.8	Gum Log Creek, mouth of, surface of water	592
32.3	Near Middle Branch, apple tree, nail in root of	597.79
32.4	Surface of water	590
33.1	Surface of water	588
33.6	Knox Bridge, 100 feet west of, in fork of road, maple tree, nail in root of	602.73
33.6	Knox Bridge, 200 feet west of S. A. Glenn's house, in chimney, bronze tablet marked "613 Atlanta"	612.241
33.6	Surface of water	588
34.3	Surface of water	587
34.3	25 feet northwest of Shoal Creek, dead stump, nail in top of	598.34
35.3	Shoal Creek, mouth of, surface of water	586
35.3	Pine stump, 200 feet north of river, nail in top of	601.72
35.4	Knox Branch, mouth of, surface of water	586
36.1	Oak tree, 900 feet north of river, nail in root of	591.83
36.5	Burton Branch, mouth of, surface of water	582
37.5	South side of river, point on bottom of cliff	588.07
37.8	Pullins Ferry, 250 feet south of, 10 feet north of road, red oak tree, nail in root of	596.59
37.8	Pullins Ferry, surface of water	581
38.4	Cleveland Shoals, head of, surface of water	578
39.6	Averys Ferry, sycamore tree 10 feet north of river, nail in root of	584.36
39.6	Foot of shoals, surface of water	578
39.8	Bottom of cliff, 2 feet south of river, point on rock	581.95

Elevations on Tugaloo River below Tallulah Falls—Continued.

Distance in miles.		Elevation in feet.
39.8	Averys Ferry, 20 feet south of river, top of cliff, in rock, bronze tablet marked "588 Atlanta"	587.443
40.3	Bradberrys Ferry, walnut tree 100 feet south of river, nail in root of	581.95
40.3	Chandlers Shoals, head of, surface of water	575
40.7	Bottom of cliff, 1 foot south of river, point on rock	577.26
40.8	Beech tree, 1 foot south of river, nail in root of	572.24
40.8	Surface of water	570
40.9	Reed Creek, mouth of, surface of water	564
41.1	Foot of Chandlers Shoals, surface of water	562
41.4	Reed Creek, 900 feet east of 10 feet south of river, nail in stump	566.95
41.7	Boat landing, birch tree, nail in root of	563.72
42.3	Hatton Shoals, head of, surface of water	560
42.8	North edge of river, F. Clark's house, 1,000 feet south of, nail in root of maple tree	556.79
42.8	Surface of water	555
43.3	Big Beaverdam Creek, 25 feet east of, nail in root of beech tree	554.01
43.3	Surface of water	546
43.7	Large pine tree, 25 feet east of small stream, 5 feet north of river, nail in root of	537.07
43.7	Surface of water	535
44.2	Hatton Ford, bottom of cliff, point on rock	526.91
44.2	Surface of water	525
44.5	Mouth of branch, surface of water	522
44.7	Mouth of branch, surface of water	519
45.3	Water oak tree, 30 feet northeast of river, nail in root of	529.36
46.3	Beech tree, 15 feet east of river, nail in root of	525.17
46.3	Surface of water	519
46.6	Burnt stump, 40 feet east of river, nail in top of	524.70
46.6	Surface of water	518
47.7	Andersonville, S. C., 0.5 mile north of, twin beech tree 15 feet north of river, nail in root of	522.27
47.8	Mouth of branch, surface of water	516
48.2	Foot of rapids, surface of water	511
48.2	Andersonville, S. C., east side of road, 200 feet east of river, northwest of Little Broadway Creek, in rock, bronze tablet marked "538 Atlanta"	537.519
48.2	"Brouris" Ferry, surface of water	510
48.2	20 feet west of river, point on rock	514.45

SAVANNAH RIVER FROM ANDERSONVILLE, S. C., TO LISBON, GA.

Savannah River, which flows between Georgia and South Carolina, is formed by the junction of Seneca and Tugaloo rivers at Andersonville, Anderson County, S. C. Tugaloo River is in turn formed by the junction of Tallulah and Chattooga rivers at a point about 3 miles below Tallulah Falls, Georgia.

Savannah River proper flows in a southeasterly direction through a rather hilly country, which is chiefly devoted to the production of cotton and corn. On the lowlands these crops are sometimes damaged by high water. The river contains many small islands, some of which are in a high state of cultivation.

During April and May, 1903, a survey of Savannah River between Andersonville, S. C., and the mouth of Broad River, near Lisbon, Ga., a distance of 42 miles, was made by Carroll Caldwell, field assistant. In the above distance there is a fall of 219 feet. The primary levels for this survey were based on the United States Geological Survey bench mark at Andersonville, S. C. Field sheets were plotted on the scale of 1:22,500, and during the course of the survey 7 tablets and 62 temporary bench marks were established, 91 water-surface elevations determined, and the following possible powers noted.

The first shoal of importance is the McDaniels Shoal, where there is a fall of 19 feet in 2½ miles. Half a mile above the foot of the shoal and at the head of Harper Island is an excellent site for a dam about 700 feet long.

At Turners Shoals there is a fall of 17 feet in about 2½ miles. These shoals begin at Kenly Ferry and extend to Craft Ferry. The river widens considerably about a mile below Kenly Ferry and has several good sites, one being on Craft Island. These shoals could be developed only at considerable expense, as a dam would have to be 1,000 feet long.

Half a mile below, the Middleton Shoals have a fall of 11 feet in 1¼ miles and offer an excellent site for a dam. The bottoms and sides are of rock.

One mile below are Gregg Shoals with a 7-foot fall in about a mile. Here the river runs between steep hills and a dam would be about 900 feet long.

Half a mile below Moseley Ferry are the Cherokee Shoals, having a fall of 18.9 feet in less than 3 miles. This is a very fine power site, as the river runs between steep hills. A dam would be about 1,000 feet long and would be placed one-fourth of a mile above the Seaboard Air Line bridge.

One and one-fourth miles below the bridge are Trotters Shoals with a fall of 69 feet in 6 miles. These are considered the finest shoals

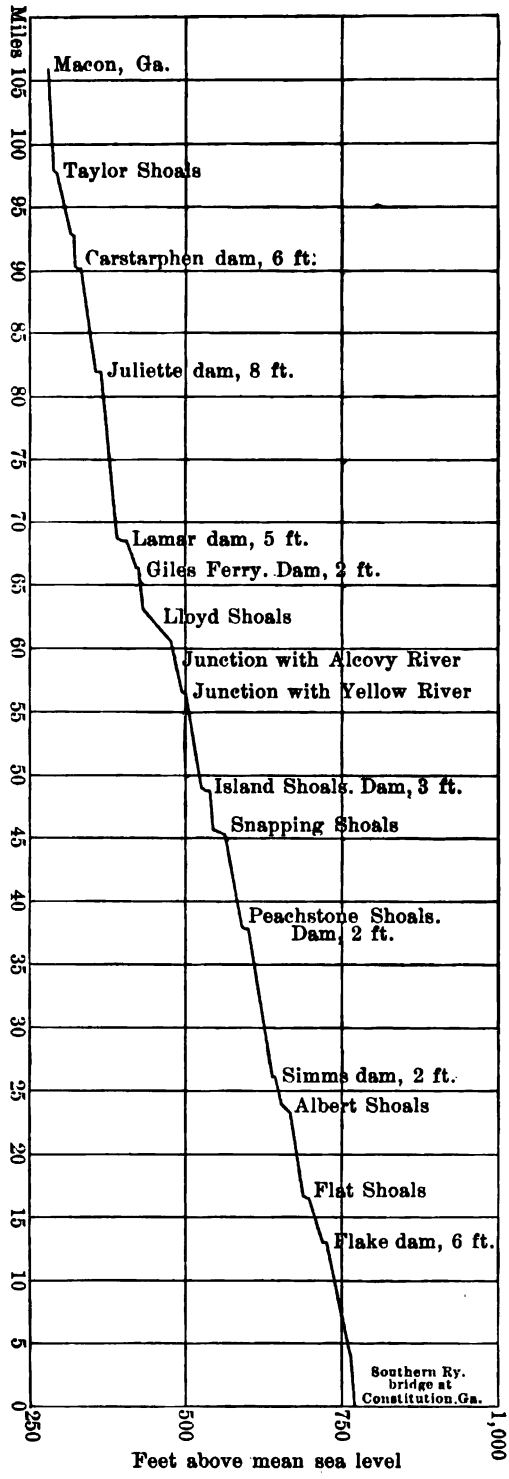
on the river. They commence at the foot of Watkins Island and run below Tates mill to Coffee Creek. In this distance there are numerous rocky bluffs where there are excellent dam sites.

From the foot of Trotters Shoals to the mouth of Broad River, the end of the survey, there is a uniform fall of 3 feet per mile.

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.[a]

Distance in miles.		Elevation in feet.
48.2	Andersonville, S. C., east side of road, 200 feet east of river, northeast of Little Broadway Creek, bronze tablet marked "538 Atlanta"	537.519
48.7	Seneca River, mouth of, surface of water	505
48.7	Small pine tree, nail in root of	512.60
49.3	Branch, mouth of, surface of water	501
49 3	Sycamore tree on edge of branch and river, nail in root of	502.78
50.5	Creek, mouth of, surface of water	497
50.6	Opposite island, 50 feet west of river, willow stump, nail in top of	503.38
50.7	Branch, mouth of, surface of water	493
51.4	In footpath, 10 feet west of river, large red oak tree, nail in root of	499.76
51.4	Lightwood Log Creek, 400 feet west of river, tripple water oak tree	507.28
52.3	Carters Ferry, surface of water	492
52.3	High water	516
52.3	Lightwood Log Creek, mouth of, surface of water	491
52.8	60 feet west of river, large walnut tree, nail in root of	501.09
53.3	Browns Ferry, 40 feet west of, double water oak tree, nail in root of	497.79
53.3	Surface of water	488
53.3	High water	499
53.3	Browns Ferry, 1,200 feet northeast of O. C. Brown's house, in brick and stone abutment at rear of, northwest corner, bronze tablet marked "518 Atlanta"	516.891
54.6	Powderbag Creek, mouth of, surface of water	487
54.8	Creek, 520 feet south of, 30 feet west of river, box elder tree, nail in root of	491.88
55	Dooley Ferry, 114 feet west of river, poplar tree, nail in root of	492.64
55	Surface of water	486
55.7	Craft Island, opposite, hanging over edge of river, maple tree, nail in root of	485.13
55.7	Surface of water	485
55.7	Long Branch, mouth of, surface of water	484
56.1	30 feet south of river, large poplar tree, nail in root of	487.61
56.1	Surface of water	482
56.1	McDowells Shoals, head of, surface of water	477
56.1	High-water mark	487
56.8	70 feet southwest of river, pine tree, nail in root of	483.26
56.8	Surface of water	474

[a] Continued from Tugaloo River elevations. See p. 28.



PROFILE OF SAVANNAH RIVER FROM ANDERSONVILLE, S. C., TO LISBON, GA.

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.—Continued.

Distance in miles.		Elevation in feet.
57.3	Turner Creek, mouth of, southwest of river, birch tree, nail in root of	473.43
57.3	Surface of water	471
57.5	20 feet southwest of river, birch tree, nail in root of	476.13
57.5	Surface of water	470
58	Harper Island, 0.1 mile west of, red oak tree bending over edge of river, nail in root of	472.57
58.7	Surface of water	466
59.1	Parks Ferry, 0.2 mile above, west side of ferry road, opposite colored house, foot of steep hill, in cliff, bronze tablet marked "495 Atlanta"	494.435
59.3	Parks Ferry, 15 feet west of river, large red oak tree, nail in root of	468.53
59.3	Surface of water	461
59.5	Surface of water	460
60.5	Mulberry tree stump, west side of river, nail in root of	462.42
60.5	Surface of water	458
60.8	Saddlers Old Ferry, 40 feet west of river, rock cliff, point on rock	466.598
60.8	Surface of water	458
60.9	60 feet south of river, hickory tree, nail in root of	471.27
60.9	Surface of water	457
61.5	Cedar Creek, 500 feet north of river, large black oak tree, nail in root of	460.66
61.5	Cedar Creek, mouth of, surface of water	455
62.3	Kinleys Ferry, 0.1 mile southwest of; 10 feet west of river, white ash tree, nail in root of	457.68
62.3	Surface of water	454
62.4	Turners Shoals, head of, surface of water	453
62.5	McMullins Branch, mouth of, surface of water	450
64.2	50 feet south of river, small hickory tree, nail in root of	456.55
64.3	Shoals, surface of water	450
65.8	200 feet west of river, black oak tree, nail in root of	459.62
65.9	Surface of water	443
66.2	25 feet west of river, black oak tree, nail in root of	445.80
66.2	Surface of water	440
66.9	Craft Ferry, 10 feet west of river, red oak tree, nail in root of	443.67
66.9	Creek, mouth of, surface of water	437
66.9	Craft Ferry, 125 feet west of boat landing, 60 feet west of river, in rock, aluminum tablet marked "450 Atlanta"	449.306
66.9	Foot of Turners Shoals, surface of water	437
68.1	Middleton Shoals, head of, surface of water	435
68.5	Barnes Island, opposite, 125 feet west of river, small black oak tree, nail in root of	443.11
68.5	Surface of water	431
68.7	300 feet west of river, on top of cliff, dogwood tree, nail in root of	457.46

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.—Continued.

Distance in miles.		Elevation in feet.
69.5	West edge of river, willow stump, nail in root of	428.03
69.8	Middleton Shoals, foot of, surface of water	424
69.8	20 feet west of river, post-oak tree, nail in root of	432.50
70.2	Powells Ferry, 20 feet west of river, water oak tree, nail in root of	435.23
70.2	Powells Ferry, surface of water	422
70.9	Surface of water	419
71	Powells Ferry, 0.8 mile south of, 150 feet west of river, white ash stob, nail in top of	439.30
71.3	Gregg Shoals, head of, surface of water	418.7
72.4	Black Ferry, 25 feet west of river, nail in root of birch tree	421.677
72.4	Black Ferry, surface of water	410.3
72.8	350 feet east of river, octagon burnt tree stump, nail in root of	431.08
73.2	Creek, mouth of, surface of water	409
73.4	350 feet east of river, persimmon tree stump, nail in root of	419.39
73.7	Branch, mouth of, surface of water	407
73.7	Mill, opposite, surface of water	406
73.8	Coldwater Creek, mouth of, surface of water	406
74.3	350 feet east of river, 140 feet southwest of small branch, persimmon tree, nail in root of	414.39
75.8	Allens Creek, mouth of, surface of water	404
76.2	Harper Ferry, 20 feet east of river, southside of road, water oak tree, nail in root of	412.26
76.2	Surface of water	403
76.2	High-water mark	416
76.4	250 feet southeast of W. J. Taylor's house, side of brook, in limestone rock, bronze tablet marked "420 Atlanta"	419.146
77	Branch, mouth of, surface of water	402
77.3	Ruckers and Tuckers Ferry, 40 feet southeast of and 5 feet west of river, willow tree, nail in side of	405.49
77.3	Surface of water	401
77.3	High-water mark	418
77.6	Surface of water	400
78.1	Surface of water	399
78.4	English Creek, 60 feet west of, 50 feet north of river, white hickory stump, nail in root of	417.13
78.4	English Creek, mouth of, surface of water	398
78.9	McCauleys Island, 900 feet south of head of, surface of water	397
79.2	McCauleys Ferry, 40 feet west of river, ash stump, nail in root of	407.19
79.2	Surface of water	397
79.6	Surface of water	396
79.6	150 feet north of river, beech tree, nail in root of	407.39
80.5	Branch, mouth of, surface of water	395
80.8	Surface of water	394

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.—Continued.

Distance in miles.		Elevation in feet.
80.8	50 feet east of river, walnut tree, nail in root of	398.77
81	Moseley Ferry, 50 feet east of river, walnut tree, nail in root of	400
81	Surface of water	392
81.3	Surface of water	392
81.6	Surface of water	391
81.7	Large falls, head of, surface of water	390
81.8	50 feet east of river, twin pine tree, nail in root of	399.23
81.9	Cherokee Shoals, surface of water	388
82.6	Surface of water	379
82.6	125 feet east of river, oak tree, nail in root of	385.75
83.2	Surface of water	374
83.3	Carter Island, ferry, 40 feet west of river, white oak tree, nail in root of	382.52
83.5	Surface of water	373
83.7	Rocky River, mouth of, surface of water	372
84.2	Surface of water	371
84.2	Seaboard Air Line bridge, abutment, east side of bridge, bronze tablet marked "383 Atlanta"	382.161
85.1	Watkins Island, lower end of, 15 feet north of river, oak tree, nail in root of	375.7
85.2	Watkins Island, 150 feet southwest of, on mainland, dead stump, nail in side of	374.59
85.2	Trotter's shoals, head of, surface of water	367
85.5	Shoals, surface of water	364
85.7	Head of island, surface of water	362
85.9	Surface of water	358
86	75 feet west of river, nail in stub	367.4
86.2	Calhoun Island, end of, surface of water	356
86.3	60 feet southwest of river, black ash tree, nail in root of	365.01
86.3	Trotters Shoals, in, surface of water	353
86.6	Surface of water	351
86.6	Cliff, bottom of, on rock, point	354.27
87.1	Calhoun Ferry, triple cedar tree, 75 feet west of river, nail in root of	348.39
87.1	Surface of water	340
87.5	Surface of water	336
87.6	50 feet southwest of river, in path, pine tree, nail in root of	341.32
88.1	Creek, mouth of, surface of water	329.7
88.3	Surface of water	328
88.6	10 feet southeast of road, Spanish oak, 400 feet west of river, nail in root of tree	338.61
88.9	Surface of water	325
89.2	Surface of water	322

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.—Continued.

Distance in miles.		Elevation in feet.
89.2	200 feet west of river, on top of steep hill, in footpath, hickory tree, nail in root of	360.67
89.7	Calhoun Ferry, 2.5 miles southeast of, 50 feet west of river, in large bronze tablet marked "320 Atlanta"	319.252
89.4	Surface of water	318
89.7	Surface of water	313
90.1	Surface of water	308
90.2	Surface of water	304
90.3	10 feet west of river, 300 feet north of old mill, water oak, nail in root of	305.90
90.3	Surface of water	301
90.4	Surface of water	299
91.3	Branch, mouth of, surface of water	292
91.3	10 feet west of river, dead birch tree, nail in root of	300.21
91.8	Surface of water	291
92.3	Creek, surface of water	289
92.8	Clarks Ferry, 200 feet west of river, water oak, copper tack in root	309.13
92.8	Surface of water	287
92.8	High-water mark	307
93.7	Creek, 1,500 feet below, surface of water	285
93.9	50 feet west of river, gum tree, copper tack in side of	299.66
94.2	Surface of water	284
96.1	Petersburg Ferry, east side of road, dead black gum, nail in root of	293.41
96.1	Broad River, mouth of, surface of water	281
96.2	South side of ferry road, water oak, nail in root of	295.77
96.4	Lisbon, in brick wall of R. L. Cade's store, bronze tablet marked "328 Atlanta"	327.85

CHATTOOGA RIVER BELOW RUSSELL, S. C.

Between July 19 and August 10, 1903, Chattooga River was surveyed from its mouth, near Tallulah Falls, Georgia, to Russell Bridge, near Russell, S. C., a distance of 30 miles. In that distance there is a fall of 809 feet. A line of secondary levels was run, based on a primary bench mark of the United States Geological Survey 3 miles below Tallulah Falls. The field sheets were plotted on the scale of 1:22,500, and during the course of the survey 23 bench marks were established and 97 water-surface elevations were noted.

Chattooga River contains many available undeveloped power sites. From its mouth to War Woman Creek, a distance of 22 miles, the river runs through a wild, rugged country, almost uninhabited. It

flows in a gorge almost the entire distance and is very narrow and swift. There are numerous dam sites in this section, as the river is almost one continuous shoal and has an average fall of 33 feet to the mile, with a fine rock bottom and cliffs on either side. The rock is excellent for building purposes.

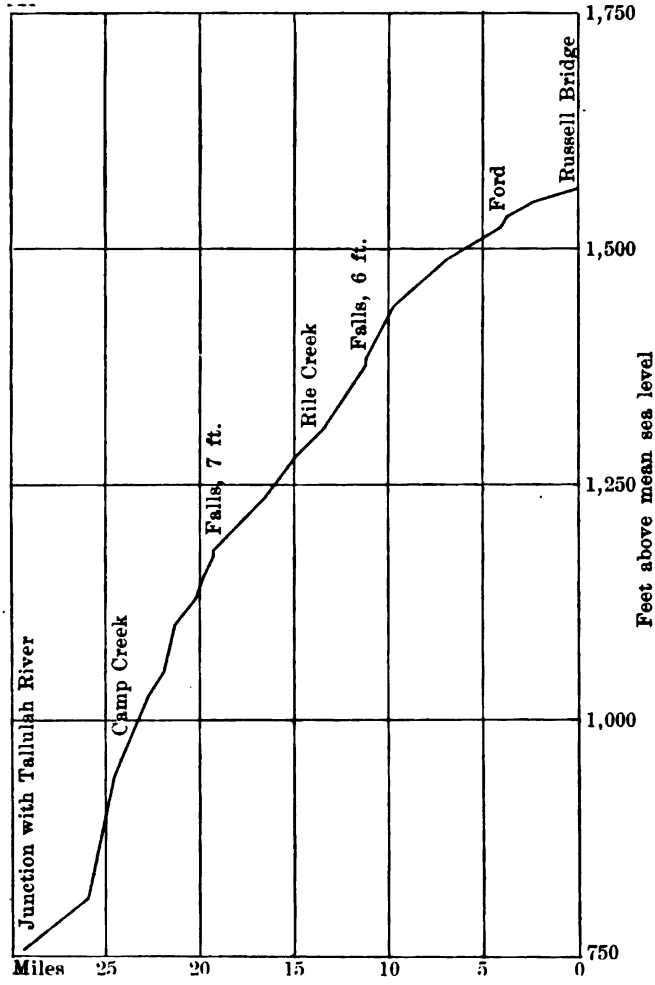


FIG. 4.—Profile of Chattooga River below Russell, S. C.

From War Woman Creek to Lone Bottom Ford, a distance of 5 miles, the bottoms widen considerably, and there are a few cultivated farms. Halfway, at Laurel Branch, there is an excellent site for a 12-foot dam, which would back water one-half mile without damage to cultivated lands. Here there is a good rock bottom and rocky bluffs on each side. From a half mile above Laurel Branch to Russell Bridge,

the end of the survey, the bottoms are considerably wider and mostly cultivated.

The elevations in the following list are based on an aluminum tablet marked "1050 M C" at Washington street entrance to the State capitol at Atlanta, the elevation of which is now accepted as 1,049.546 feet above mean sea level. The initial point upon which these levels depend is a bench mark of primary levels of Tugaloo and Savannah River surveys at the mouth of Chattooga River. The elevations accord with the 1903 adjustment.

The leveling was done under the direction of Carroll Caldwell, field assistant, by Thomas B. O'Hagan, levelman.

Elevations on Chattooga River from its mouth to Russell Bridge, Ga., 0.7 mile north of Russell, S. C.

Distance in miles.		Elevation in feet.
0.0	Tallulah and Chattooga rivers, 100 feet north of junction, point on rock	761.29
.0	Tallulah and Chattooga rivers, white oak tree 75 feet west of junction of, 25 feet north of Tallulah River, nail in root of oak tree	762.21
.0	Surface of water	754
.2	Surface of water	759
.7	Mouth of stream, surface of water	763
1	Worse Creek, mouth of, surface of water	765
1.2	Surface of water	766
1.9	Small stream on north edge of river, Spanish oak, nail in root of	776.27
1.9	Surface of water	772
2.1	Surface of water	775
2.6	North side of river, point on rock	788.63
3	Surface of water	779
4	East side of river, point on rock	851.51
4	Surface of water	849
4.1	Surface of water	869
4.5	Creek, mouth of, surface of water	892
4.7	Surface of water	899
4.9	East side of river, point on rock	918.27
4.9	Surface of water	919
5	Surface of water	929
5.1	Surface of water	939
5.2	Surface of water	949
5.3	Mouth of stream, head of shoals, surface of water	954
5.6	Camp Creek, mouth of, surface of water	961
5.6	Trail Ford, point on rock 20 feet east of river	967.50
5.6	Trail Ford, surface of water	962
5.8	Surface of water	969

Elevations on Chattooga River from its mouth to Russell Bridge, Ga., 0.7 mile north of Russell, S. C.—Continued.

Distance in miles.		Elevation in feet.
6.1	Surface of water	979
6.3	Surface of water	989
6.7	Surface of water	999
7	Surface of water	1,000
7.2	Surface of water	1,029
7.4	Cliff Creek, mouth of, surface of water	1,035
7.4	Cliff Creek, 500 feet above, east side river, point on rock	1,045.26
7.5	Surface of water	1,039
7.6	Chechero Creek, mouth of, surface of water	1,049
7.8	Surface of water	1,059
8	Surface of water	1,069
8.2	Surface of water	1,079
8.4	Surface of water	1,089
8.5	Surface of water	1,099
8.6	Surface of water	1,109
9	Surface of water	1,119
9.5	Surface of water	1,129
9.8	Surface of water	1,149
10	East side of river on edge of bank, point on rock	1,152.43
10	Surface of water	1,159
10	Iron bridge, South Carolina side, iron bar under bridge, point on	1,168.95
10	Iron bridge, surface of water	1,166.3
10	High water	1,177
10.5	Surface of water	1,169
10.6	Mouth of creek, surface of water	1,173
10.6	Head of falls, surface of water	1,179
10.8	Mouth of stream, surface of water	1,183
11	Surface of water	1,189
11.4	Surface of water	1,199
11.7	Mouth of stream, surface of water	1,204
12	Surface of water	1,209
12.5	50 feet south of island, east side of river, 10 feet from bank, point on rock	1,217.86
12.7	Surface of water	1,219
12.9	Surface of water	1,223
13	Surface of water	1,229
13.2	Stream, mouth of, surface of water	1,232
13.6	Surface of water	1,239
13.8	South Carolina side of river, at large cliff, point on rock	1,245.53
14	Surface of water	1,249
14	Mouth of Fall Creek, surface of water	1,262

Elevations on Chattooga River from its mouth to Russell Bridge, Ga., 0.7 mile north of Russell, S. C.—Continued.

Distance in miles.		Elevation in feet.
14.5	Surface of water	1,268
14.7	Surface of water	1,279
15	Surface of water	1,289
15.7	Surface of water	1,296
16	Surface of water	1,299
16.6	Rich Creek, mouth, surface of water	1,308
16.8	Surface of water	1,309
16.9	South Carolina side of river, point on rock	1,310.4
17	Surface of water	1,319
17.4	Surface of water	1,329
17.8	Sandy Bottom, 1,000 feet below, east side of river, point on rock	1,332
18	Surface of water	1,340
18.7	Surface of water	1,359
18.7	East side of river, point on rock	1,366.45
18.9	Surface of water	1,360
19.1	300 feet below falls, at bend in river, point on rock	1,376.19
19.2	Foot of falls, surface of water	1,375
19	Head of falls, surface of water	1,381
19.7	Surface of water	1,399
19.8	Rock Creek, mouth of, surface of water	1,406
20	Sandy Ford, surface of water	1,411
20	Sandy Ford, 75 feet north of, 15 feet east of river, nail in root of white oak tree	1,416.55
20.2	Surface of water	1,419
20.6	Surface of water	1,429
20.7	Dick Creek, mouth of, surface of water	1,439
20.8	Surface of water	1,449
21	East side of river, point on rock	1,452.91
21.2	Surface of water	1,459
22	Surface of water	1,469
22.1	Surface of water	1,473
22.3	4 feet east of river, nail in root of large pine tree	1,481.86
22.7	Surface of water	1,479
23	Earl Ford, 100 feet below ford, east side of river, point on rock	1,486.74
23	Surface of water	1,486
23	War Woman Creek, mouth of, surface of water	1,486
23.8	South side of river, point on rock	1,494.13
23.8	Surface of water	1,492
24.8	Surface of water	1,499
25.2	West side of river, point on rock	1,510.51
25.2	Surface of water	1,505

Elevations on Chattooga River from its mouth to Russell Bridge, Ga., 0.7 mile north of Russell, S. C.—Continued.

Distance in miles.		Elevation in feet.
26	Horseback Ford, surface of water	1,518
26.3	Surface of water	1,519
26.4	Ford, 65 feet above, north side of river, nail in live stub (white oak tree)	1,522.66
26.4	Surface of water	1,521
26.8	Surface of water	1,529
27.1	Surface of water	1,539
27.9	Barlow Stream, center of river, point on rock	1,547.26
28	Surface of water	1,549
28.7	Long Bottom Ford, east side, nail in fork of sugar maple tree	1,557.68
29.7	Small stream, mouth of river at, surface of water	1,554
30.6	West Fork, mouth of, surface of water	1,563
30.6	Wooden bridge, above Russell, S. C., southwest side of bridge, point on bolt	1,584.84
30.6	Bridge, surface of water	1,564

BROAD RIVER BELOW CARNESVILLE, GA.

Between June 9 and July 16, 1903, Broad River was surveyed from its mouth, near Lisbon, Ga., to Harrison Bridge, near Carnesville, Ga., a distance of 64½ miles. In that distance there is a fall of 316 feet. The field sheets were plotted on the scale of 1:22,500, and the survey was accompanied with a line of secondary levels based on the primary bench mark of the United States Geological Survey at Lisbon, Ga. During the course of the survey 54 bench marks were established and 109 water elevations determined.

The flow is very gradual from the mouth to Milford Shoals, a distance of 2 miles. These shoals have a fall of 8 feet in a distance of one-third of a mile, and are about 500 feet wide. The river bottoms are wide up to the foot of Anthony Shoals, 5¼ miles from the mouth of the river. Here is the finest power site on the river, there being a fall of 58 feet in 1¾ miles, with rock bottom and rock bluffs on each side. A dam at this point would have to be 1,000 feet long. The rock is granite and would furnish excellent material for building purposes. At the end of these shoals, on the Elbert County side, are the remains of a wing dam which furnished power for a cotton mill now in ruins.

From here to Fishdam Shoals, 9¼ miles, the river has a fall of 9 feet, with wide, cultivated bottoms on either side for most of the distance. At Fishdam there is a 3-foot dam about 250 feet long which furnishes power for a grist and saw mill.

From Fishdam to the mouth of South Broad River, 15½ miles, there is a fall of 23 feet with no shoal of any consequence. The bottoms are wide in most places and are in a high state of cultivation.

One mile above South Broad River are the Detwiler Shoals, with a fall of 7 feet in half a mile. A dam at this point would be about 300 feet long. A mile and a half farther are the lower Moore Shoals, with a fall of 6 feet in a quarter of a mile, and good outcrop of hard rock on both sides. A dam here would be about 350 feet long.

Five miles farther up are the Payton Shoals, with a fall of 4 feet in a quarter of a mile. Here the steep banks show granite on the southeast side.

Two and one-half miles upstream are the Cowpen Shoals, with a fall of 8 feet. This is an excellent site for a dam, having rock bottom and sides. Two miles upstream are Moore Shoals, with a fall

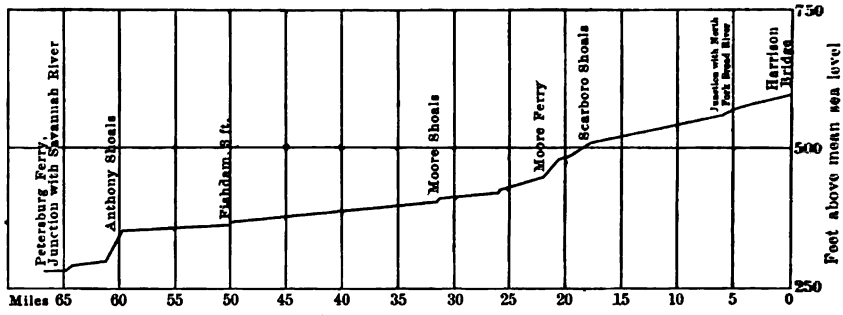


FIG. 5.—Profile of Broad River below Carnesville, Ga.

of 19 feet in three-fourths of a mile. The river here is about 400 feet wide, with solid rock bluffs on either side.

One-half mile beyond are Brown Shoals, with a 10-foot fall in one-third of a mile. A dam here would be about 400 feet long and would have an excellent foundation. One and three-fourths miles upstream are the Bryant Shoals, with a fall of 20 feet in 1¼ miles. This is an excellent site for a dam, having good bottoms and rock sides.

For 12 miles upstream to Double Bridge the shoals are small and do not seem important. From Double Bridge to Harrison Bridge, at which point the survey ended, a distance of 6 miles, the river is very narrow and shoaly, but the volume of water is small.

The elevations in the following list are based on a bronze tablet in a brick wall of R. L. Cade's store at Lisbon, Ga., marked "Atlanta 328," the elevation of which is accepted as 327.850 feet above mean sea level. They accord with the 1903 adjustment of the precise-level net.

The leveling was done under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville.

Distance in miles.		Elevation in feet.
0.0	Lisbon, mouth of Broad River, 870 feet northwest of, south side of ferry road, nail in twin water oak	295.77
.0	Broad River, mouth of, surface of water	280
.0	Broad River, 870 feet northwest of mouth, high-water bench mark	300
.6	Small stream, near, surface of water	281
1.4	Mill Ford Shoals, foot of, surface of waters	281
2.1	Mill Ford Shoals, middle of, surface of water	288
2.4	Mill Ford Shoals, head of, surface of water	289
2.4	Mill Ford Shoals, 200 feet east of river, near 5-inch elm tree, nail in live stob	304.9
2.7	Center of bend, surface of water	291
3.4	Dubose Ferry, 300 feet above, surface of water	292
4.7	Anthony Shoals, foot of, surface of water	293
5	Anthony Shoals, surface of water	295
5.2	Anthony Shoals, at large bend in river, surface of water	307
5.2	Anthony Shoals, at rock cliff, surface of water	310
5.2	Anthony Shoals, at rock cliff, point on rock, 1 foot west of river	311.57
5.4	Anthony Shoals, surface of water	319
5.6	Anthony Shoals, surface of water	329
5.8	Anthony Shoals, in front of old factory, surface of water	339
6	Anthony Shoals, at old dam, east edge of river, nail in root of birch tree	347.77
6	Anthony Shoals, surface of water	351
6.4	Anthony Shoals, head of, surface of water	355
6.5	Burton Ferry, 6 feet south of river, nail in root of Spanish oak tree	361.44
6.5	Surface of water	355
6.5	Burton Ferry, high water	364
7.1	Surface of water	355
8.7	Mouth of creek, surface of water	356
8.7	60 feet south of river, 25 feet east of creek, nail in sweet gum tree	367.59
10	Surface of water	356
10.9	Bakers Ferry, small shoals, surface of water	356
11	Bakers Ferry, 20 feet southwest of river, nail in root of large birch tree	364
11	Bakers Ferry, surface of water	357
11.8	Wahache Creek, mouth of, surface of water	360
13.8	Bells Bridge, north side, nail in joist	373.69
13.8	Bells Bridge, surface of water	360
13.8	Bells Bridge, high water	386
13.8	Bells Bridge, floor of	393.2
15	Bells Bridge, 250 feet north of river, large pine tree near path to river, nail in tree	375.34
15.4	Mouth of small stream, surface of water	361
15.6	Falling Creek, mouth of, surface of water	362

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville—Continued.

Distance in miles.		Elevation in feet.
16	Foot of shoals, surface of water	363
16.4	Fishdam, foot of, surface of water	365
16.4	Fishdam, head of, surface of water	368
16.4	Fishdam Ferry, north side river, nail in root of large water oak tree	374.35
16.4	Fishdam Ferry, surface of water	368
16.4	Fishdam Ferry, south side of, nail in root of gum tree	374.87
17.7	Surface of water	368
18.9	North of river, point on rock	386.66
18.9	Surface of water	370
20	Grimes old ferry, edge of river, nail in root of white oak tree	375.51
20	Grimes old ferry, surface of water	371
21.3	500 feet south of river, river road, 25 feet south of, nail in root of Spanish oak	388.89
22.1	Mouth of large creek, surface of water	372.8
22.5	Pinegrove, 400 feet north of river, 900 feet west of large creek, nail in root of pine tree	398.51
23.1	Mattox Bridge, north side, nail in plank	401.35
23.1	Mattox Bridge, surface of water	374
23.1	Bridge floor	404
23.1	High water	400
24.8	Rock cliff, near, 40 feet south of river, nail in root of gum tree	397.88
24.8	Surface of water	377
25.2	Jones Ferry, east side, nail in root of water oak tree	393.43
25.2	Jones Ferry, surface of water	377
25.2	High-water mark	401
25.5	Jones Ferry, 0.3 mile above, 40 feet west of river, nail in white oak tree	394.38
26	Surface of water	380
26.7	Millstone Creek, mouth of, 60 feet east of, 25 feet south of river, nail in side of box elder	392.64
26.7	Millstone Creek, mouth of, surface of water	381
28	Gold Mine Cliff, surface of water	384
28.5	Horseshoe Bend, head of, 150 feet south of river, in cornfield, nail in Spanish oak	405.67
28.5	Dove Creek, mouth of, surface of water	386
28.6	Bend in river, surface of water	396.4
28.6	Surface of water	386
30	260 feet north of river, nail in root of pine tree	411.3
30.9	Surface of water	391
31	Martins old ferry, near spring, point on rock	420.14
31.3	Junction South Fork and Broad River, southeast point of rivers, nail in side of birch tree	395.86
31.3	Surface of water	391

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville—Continued.

Distance in miles.		Elevation in feet.
32.4	Detwiler Ferry, foot of shoals, surface of water	395
32.9	Detwiler Ferry, east side, edge of water, slanting Spanish oak, nail in	406.07
32.9	Detwiler Ferry, head of shoals, surface of water	402.1
32.9	Detwiler Ferry, high water	423.6
33.4	Seaboard Air Line bridge, abutment, east side of river, 350 feet from	420.28
33.4	Seaboard Air Line bridge, surface of water	402
34	Moore Shoals, surface of water	404
34.4	Old mill, 25 feet east of river, point on rock	416.23
34.4	Old mill, mouth of stream, surface of water	409
34.4	Moore Shoals, head of, surface of water	411
34.7	Bells Ferry, edge of river, 2 feet from road, overhanging Spanish oak, nail in	418.87
34.7	Bells Ferry, surface of water	412.3
34.7	Bells Ferry, high water	430
35.9	Harpers Ferry, north side of river, east side ferry, nail in root of black gum tree	422.54
35.9	Harpers Ferry, surface of water	414
35.9	Harpers Ferry, high water	432
36.8	Holly Branch, mouth of, surface of water	416
37.5	Moon Ferry, east of ferry, nail in side of white oak tree	423.19
37.5	Moon Ferry, surface of water	418
37.8	Surface of water	419
37.9	Mouth of creek, surface of water	420
38.6	Payton Shoals, foot of, surface of water	422
39	Payton Shoals, east side of river, nail in sycamore tree	428.57
39	Payton Shoals, head of shoals, surface of water	425
39.1	South Payton Ferry, 25 feet from river, east side of ferry, nail in side of dead willow tree	431.35
39.1	Payton Ferry, high water	449
39.1	Payton Ferry, surface of water	427
39.1	Payton Ferry, high water	449
39.4	Payton No. 2, head of shoals, surface of water	429
39.8	Victory Ferry, overhanging birch tree, nail in side of	432.17
39.8	Victory Ferry, surface of water	430
39.8	High water	450
40.4	Moon Ferry, nail in root of white oak tree	442.62
40.4	Moon Ferry, foot of shoals, surface of water	431
40.5	Moons Shoals, head of, surface of water	433
41.1	Bend in river, 1,500 feet east of Mill Creek, east side river, point on rock	443.14
41.1	Surface of water	438

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville—Continued.

Distance in miles.		Elevation in feet.
41.4	Mill Shoal Creek, mouth of, surface of water	439
41.4	Surface of water	441
42.2	Head of shoals, surface of water	450
42.7	Moore Ferry, west side of, large spruce oak tree, nail	455.77
42.7	Moore Ferry, surface of water	450
42.7	High water	460
43.0	Moore Shoal, at spring, foot of shoals, surface of water	454
43.3	Shoals, surface of water	462
43.3	Moore Shoals, near head of, point on rock	470
43.8	Browns Ferry, burnt stump northeast of river, nail in	482.09
43.8	Browns Ferry, near head of Moors shoals, surface of water	471
44.2	Moore Shoals, head of, surface of water	482
44.6	Dudleys Shoals, east bank of river, point on rock	489.28
44.6	Surface of water	482
45.5	Dudley Ferry, black gum tree north side of ferry, nail in root	502
45.5	Dudley Ferry, surface of water	487
45.5	High-water mark	504
45.6	Bryant Shoals, foot of, surface of water	489
46.2	Bryant Shoals, head of, surface of water	496
46.5	Sawmill, Spanish oak tree, 50 feet from river, nail in root of	506.65
46.5	Surface of water	502
46.5	Head of shoals, surface of water	506
47.7	Bluestone Creek, north side river, 1.2 miles below Bluestone Creek, point on rock	518.38
47.7	Surface of water	512
48.9	Mouth of Bluestone Creek, surface of water	617
49.6	Surface of water	521
50.4	New Lattice Bridge, east side of river, nail in floor of	546.44
50.4	Bridge floor	548.8
50.4	Bridge, surface of water	523
50.4	High-water mark	548.1
51.2	Mouth of stream, foot of shoals, surface of water	523.7
51.6	Head of shoals, surface of water	526
52.3	Winters Creek, just below bend in river, surface of water, temporary bench mark	545
52.4	Winters Creek, mouth of, head of shoals, surface of water	529
53.2	Surface of water	532
53.9	Mouth of stream, surface of water	535
54.7	Bragg Ferry, 2 feet from river, nail in root large red oak tree	541.75
54.7	Bragg Ferry, mouth of Hudson River, surface of water	537
54.7	High-water mark	567

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville—Continued.

Distance in miles.		Elevation in feet.
55.2	Surface of water	541
55.7	Dove Bridge, southeast corner of, nail in side of white oak tree	561.78
55.7	Dove Bridge, surface of water	542
55.7	High water	569
57.2	Foot of shoals, surface of water	548
57.3	Head of shoals, surface of water	552
57.6	Surface of water	554
57.7	Creek, 60 feet southeast of mouth of, nail in white oak	563.30
57.7	Creek, mouth of, surface of water	556
58.1	Mouth of stream, surface of water	556
58.8	Middle Broad and Broad rivers, forks of, walnut tree 75 feet west of fork, nail in side	575.16
58.8	Surface of water	557
59.1	Double Bridge, northwest side of, nail in plank	581.11
59.1	Surface of water	563
59.1	High-water mark	576
59.1	Bridge floor	584
59.7	Head of shoals, surface of water	570
59.9	Surface of water	573
60.6	Corey Creek, 0.6 mile below, large rock projecting out from bank point on	581.02
60.9	Small shoals in river, surface of water	580
60.9	Corey Creek, mouth of, surface of water	581
61.5	Bend, on east side river, point on rock	591.15
61.5	Surface of water	584
62.1	Fish dam, surface of water	586
62.2	Surface of water	588
62.3	Bend in river, east side, point on rock cliff	598.59
62.8	Philip Shoals, head of, surface of water	591
63.2	Stephens Creek, mouth of, surface of water	592
63.4	Ford, oak tree 75 feet north of, nail in north side of	603.49
63.4	Surface of water	593
63.4	Surface of water	594
64.6	Harrison Bridge, east of, north of river, nail in root of Spanish oak tree	607.07
64.6	Surface of water	596
64.6	Bridge floor	613.7
64.6	High-water mark	612

SOUTH AND OCMULGEE RIVERS, FROM CONSTITUTION TO MACON, GA.

South and Ocmulgee rivers were surveyed from Constitution to Macon, Ga. For the first 28 miles the topography was plotted on the scale of 1:45,000, but subsequently on the standard scale of 1:22,500. The levels are secondary levels based on the United States Geological Survey permanent bench mark at Constitution, Ga. Eighty-six bench marks were established and 200 water-surface elevations were recorded.

South River rises in the city of Atlanta and flows in a southeasterly direction for 56½ miles and then joins Yellow River to form the Ocmulgee. For 11 or 12 miles below Constitution, the beginning of the survey, the river is narrow, being about 15 feet wide at places. All along the north side of the river in this stretch are extensive beds of clay, which at certain points are being used for brickmaking.

Flakes' mill, 11 miles from Constitution, is the first power now utilized on the river. At this point the dam is 6 feet high. Below for 6 miles the river remains shoaly and narrow until Flat Shoal is reached, where there is a fall of 12 feet with a small gristmill using a little of the power. Near here the river is very crooked and incloses in its large loops flat, sandy stretches of country, which are very fertile. Near Flat Shoal is Littlestone Mountain, with valuable granite quarries.

At Albert Shoals, 7 miles farther down, there is a fall of 16 feet in half a mile. The river is here about 125 feet wide and the volume is much increased by a number of tributary streams. The banks are sloping, with no rock visible. The power site has recently been purchased by a company which proposes to develop it.

At Simm's mill, 3 miles below, is a small 2-foot dam. From here to Peachstone Shoals, a distance of 11 miles, there is a fall of 32 feet, the river winding through good bottom lands. Camp and Honey creeks enter the river in this stretch and add a large amount of water. At Peachstone Shoals is a 2-foot dam which backs the water for one-half mile, and with a canal about 400 feet long develops a head of about 9 feet, the power from which drives several turbines operating a grist and a saw mill. Soft rock is visible on the west bank, while the east bank is a flat sand bar.

About 8 miles below are the Snapping Shoals, where there is a fall of 20 feet in a distance of 300 yards. Near the lower end of the rapids several small islands divide the channel into several parts. Solid rock is close to the surface on both sides of the river. A portion of the power at this point is used in operating a large roller flour mill and sawmill. Mr. DeLoach, the owner, is taking steps

to develop all the power and intends erecting a large cotton factory at this point.

Three miles below here is Island Shoal, with a fall of 10 feet in 250 yards. Here there is a flour mill and a furniture factory, both operated by a 3-foot dam with a canal 1,200 feet long. The head could be increased by adding 5 feet more to this dam without materially damaging any property above. This site is an excellent location for power development, as the banks are high and solid and the length of the dam would probably not exceed 250 feet.

Eight miles farther down is the Barnes Shoal, at the mouth of Yellow River. A dam here would be about 700 feet long. There are excellent foundations and about a 9-foot fall.

Farther down the stream are Keys Shoals, with a 3-foot fall and several minor riffles to Lloyds Shoals, which has a fall of 43 feet in about 2½ miles, at the lower end of which there is a good dam site. The river at this point is only about 350 feet wide, with solid rocky banks rising 50 feet on either side. A 45-foot dam at this point would do a trifling amount of damage to property above.

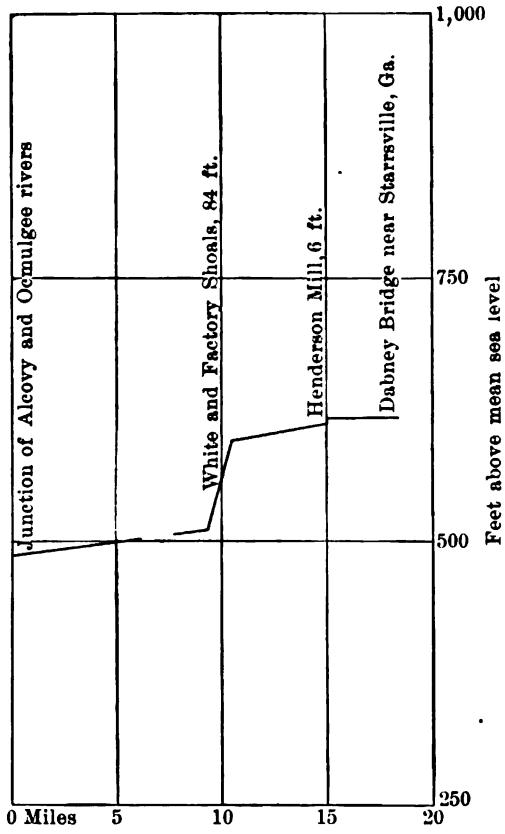


FIG. 6.—Profile of South and Ocmulgee rivers from Constitution to Macon, Ga.

Ten miles downstream is Smith Shoal, with a fall of 12 feet, where a 2-foot dam and a long canal at present run Smith's gristmill. At Lamars Shoals, 2 miles below, there is a fall of 19 feet in 1 mile with a 5-foot dam and a canal running a flour mill. The river is here about 1,000 feet wide, with high, rocky banks, and has a number of small islands and large rocks scattered all through it. Twelve miles farther down, at Juliette, Ga., is an important shoal which has been developed by Doctor Glover. There is a 15-foot fall in one-half mile, which has been developed by an 8-foot dam with a short canal,

and runs the Glover cotton mills and the Juliette Milling Company's plant.

Twelve miles below are Dames Shoals, with an 8-foot fall in 600 feet. A 6-foot dam at this point supplies Carstarphens gristmill, which is a large wholesale plant. The bed of the river here is solid rock, but a higher dam would flood valuable bottom lands above.

Popes Shoals have a 5-foot fall in a quarter of a mile, and Taylor's shoals have a 5-foot fall within a few hundred yards.

The elevations in the following lists are based upon an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta marked "1050 M C," the elevation of which is accepted as 1,049.546 feet above mean sea level. The leveling on South and Ocmulgee rivers is adjusted to accord with elevations of precise level bench marks at Constitution, Holton, and Macon, Ga., by the 1903 adjustment.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, level man.

Elevations on South River from Constitution to junction with Yellow River (head of Ocmulgee River) near Worthville.

Distance in miles.		Elevation in feet.
0.0	Constitution, 25 feet south of Southern Railroad, 4 feet east of sign-board, iron post marked "847 Morehead 1898"	847.006
.0	Surface of water	772
2	Intrenchment Creek, mouth of, nail in root of black gum	773.77
2	Surface of water	770
2.8	McNeals Bridge, nail in root of sycamore tree	769.57
2.8	Surface of water	768
7	Kellers Bridge, north end, iron bolt	751.92
7	Surface of water	750
10	Shoal Creek bridge, surface of water	737
12.6	Flake's mill, nail in root of birch tree	733.26
12.6	Surface of water	728
16.3	Flat Shoal Bridge, south side of river, east side of approach, on stone abutment	708.71
16.3	Surface of water	698
	Foot of shoal	686
20.6	Parkers Bridge, nail in root of sweet-gum tree	678.76
20.6	Surface of water	672
23.6	Daniels Bridge, lower side, right end of, point of stone pier	667.97
23.6	Surface of water	649
25.3	Simms Bridge, surface of water	635
26.4	Knight Creek, 50 feet above mouth, on root of sycamore, nail	639.28
26.4	Surface of water	629

Elevations on South River from Constitution to junction with Yellow River (head of Ocmulgee River) near Worthville—Continued.

Distance in miles.		Elevation in feet.
31	Oglesbys Bridge, 25 feet above, nail in root of oak tree	622.02
31	Surface of water	614
36	Peachstone Falls, nail in root of water oak	605.71
36	Peachstone Shoals, head of, surface of water	597
	Peachstone Shoals, foot of, surface of water	589
41	Butler Bridge, 30 feet below, nail in root of red-oak tree	587.15
41	Surface of water	569
43	Snapping Shoals, head of, surface of water	562
43.1	Snapping Shoals Bridge, 40 feet from north approach, on root of water oak	559.66
	Snapping Shoals, foot of, surface of water	542
	Island Shoals, head of, surface of water	536
45.3	Island Shoals Bridge, near south approach of, nail in root of white oak	534.89
45.3	Surface of water	525
50.8	Manns Bridge, on south side of river, 20 feet below, nail in root of hickory tree	518.49
50.8	Surface of water	503
52.1	Yellow River, mouth of, opposite, nail in root of pine tree	506.94
52.1	Surface of water	498

Elevations on Ocmulgee River from head, at junction of South and Yellow rivers, near Worthville, to Macon.

Distance in miles.		Elevation in feet.
0.0	Yellow River, opposite mouth of, nail in root of pine	506.94
.0	Surface of water	498
	Alcovy River, opposite mouth of, nail in root of large white oak	494.27
	Surface of water	484
4.1	Tusahaw Creek, mouth of, head of Lloyds Shoals, nail in root of water oak	482.12
4.1	Surface of water	472
6.4	Lloyds Shoals, foot of, surface of water	429
7.4	Pittmans Ferry, near south side of, nail in root of beech tree	434.96
7.4	Surface of water	425
7.9	Yellow Water Creek, 30 feet above mouth of, nail in root of hickory tree	433.97
7.9	Surface of water	422
9.2	Giles Ferry, nail in root of pine tree	430.01
9.2	Surface of water	420

Elevations on Ocmulgee River from head, at junction of South and Yellow rivers, near Worthville, to Macon—Continued.

Distance in miles.		Elevation in feet.
9.2	Smiths Shoals, head of, surface of water	420
10.7	Smiths Shoals, foot of, surface of water	408
10.9	Smiths Ferry, on south side, 20 feet above landing, nail in root of ash tree	410.44
10.9	Surface of water	407
11.9	Lemars Shoals, head of, surface of water	406
11.9	Lemars Shoals, foot of, surface of water	387
14.1	Goodmans Ferry, south side of river, nail in root of large red oak tree	400.74
14.1	Surface of water	382
17.8	Wards Ferry, south side of river, nail in root of water oak	392.68
17.8	Surface of water	375
19.4	Big Sandy Creek, Southern Railway bridge over, 4 feet south of rail, 2 feet from east end bridge, point on stone pier	399.45
19.4	Surface of water	374
22.5	Bridges Ferry, south side of river, nail in root of large water oak tree	382.82
22.5	Surface of water	370
22.9	South bank river, 10 feet from water, nail in root of large oak tree	388.15
22.9	Surface of water	368
24.4	Towaliga River, south bank at mouth of, nail in root of red oak	379.34
24.4	Surface of water	368
25.4	Glovers Shoals, head of, surface of water	366
25.9	Glovers Shoals, foot of, surface of water	351
27.3	Glovers Ferry, 10 feet south of west approach, nail in root of beech tree	361.10
27.3	Surface of water	346
28.5	Mitchells Ferry, 10 feet south of west end, nail in root of red oak tree	361.74
28.5	Surface of water	344
32.4	25 feet from river, opposite milepost, nail in root of thunderwood tree	340.79
32.4	Surface of water	330
33.9	Danns Ferry, 10 feet south of west end of, nail in root of ash tree	335.63
33.9	Surface of water	328
34.9	Carstarphens Shoals and dam, head of, surface of water	328
	Foot of dam, surface of water	322
35	Foot of shoals, surface of water	320
36.4	Rum Creek, north abutment west end of Southern Railway bridge over	347.32
36.4	Surface of water	318
36.9	Popes Station, in front of, top of west rail	348.23
36.9	Popes Ferry, south end of, nail in root of water oak	326.88
36.9	Surface of water	318
37.9	Head of shoals, surface of water	317
37.9	Foot of shoals, surface of water	312

Elevations on Ocmulgee River from head, at junction of South and Yellow rivers, near Worthville, to Macon—Continued.

Distance in miles.		Elevation in feet.
41.9	Holton, 35 feet north of station; 29 feet west of center of track, iron post marked "339 Morehead 1898"	338.733
41.9	Surface of water	299
47.7	Virgin, west rail of upper switch of Southern Railway at	322.52
47.7	Surface of water	282
49.9	Macon waterworks, just below, 30 feet east of track, 100 feet below mouth of small creek on south side of river, nail in root of pine tree	301.88
49.9	Surface of water	278
54.9	Macon, post-office building, at corner of Mulberry and Third streets, at left of Mulberry street entrance, in water table, aluminum tablet marked "334 Morehead 1898"	333.942

YELLOW RIVER BELOW YELLOW RIVER, GA.

Yellow River was surveyed from its mouth, near Worthville, Ga., upstream to Simmons's mill, near Yellow River, Ga., a distance of 57 miles. The scale upon which the field work is plotted is 1:22,500. During the course of the survey 54 bench marks were established and 103 water-surface elevations obtained.

Yellow River flows in a southeasterly direction and contains some valuable power sites, both developed and in a natural condition. One-half mile above its mouth are the Indian Fishery Shoals, where there is a fall of 12 feet in about 200 feet. The river is here about 300 feet wide, but a narrow neck projecting just below the shoals and several rocky islands considerably reduce the probable expense of construction. There is a gristmill and a cotton gin in operation here, using perhaps nine-tenths of the available power.

For 18 miles above the river runs between high banks, alternating with low bottoms to Langdon Shoals, without any marked shoals except at Lees, where there is a fall of 2½ feet, and Flat Shoals, with a 1-foot fall. Langdon Shoals have only a 4-foot fall.

Three miles above, at Porterdale, is the finest power site on the river, where extensive developments have been made by the Bibb Manufacturing Company, which has a large cotton and twine factory at this point. Here there is a fall of 67 feet in half a mile, with a 12-foot dam at the upper end of the shoal. The banks at the foot are very high, but gradually become lower until just above the dam large bottoms begin and continue for 5 miles. Five miles above the Georgia Railroad is the next power, McDaniels Shoals, where there is a 7-foot fall in a very short distance, and a 6-foot dam operating a gristmill. The north bank is solid rock, sloping gently, but

the south bank shows no outcrop. The power developed by this dam could be much increased with small cost.

Above this point the bottoms become narrower and the river banks more rugged and higher until at Milstead, Ga., 4½ miles above, there is a fall of 45 feet in half a mile. A 15-foot dam, with canal, is completed here, and two large cotton factories are being constructed. Railroad facilities have recently made this a valuable site for mills, and a large granite quarry has been opened up at the same point.

Eleven miles above are Anniestown Shoals, with a 23-foot fall, where there is an 11-foot dam, which formerly supplied power used to operate a cotton mill of the old type. The banks here are all hard, unseamed rock, and the site could be developed into valuable property.

Two and one-half miles above are some shoals with a 14-foot fall in half a mile. The power is undeveloped, but is in a rather inaccessible

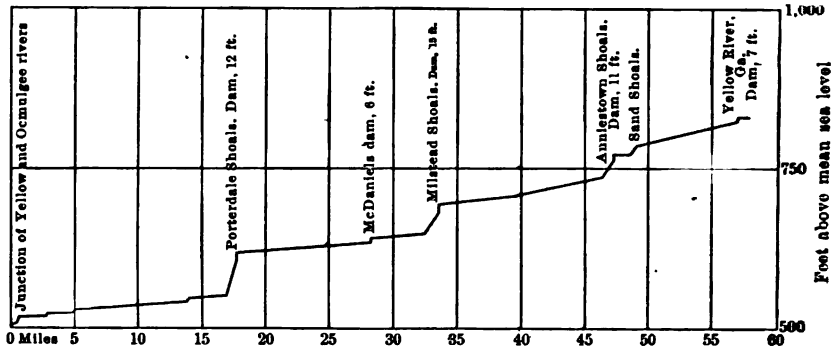


FIG. 7.—Profile of Yellow River below Yellow River, Ga.

section of the country. Above this point the river flows through a very rough country for 10 miles, passing no important shoals until the next power is reached, at Yellow River, Ga., the end of the survey. Here is a dam 7.3 feet high, which operates the Simmons roller mills. The lower reaches of the river are thickly settled, cotton and grain being the principal crops, but the upper part of the river is almost entirely in timber land.

The elevations in the following list are based on an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta, marked "1,050 M C," the elevation of which is accepted as 1,049.546 feet above mean sea level. The initial point of this list is a bench mark of flying levels on Ocmulgee River.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Yellow River from mouth near Worthville to Yellow River, Ga.

Distance in miles.		Elevation in feet.
0.0	Yellow River, mouth of, opposite, nail in root of pine tree	506.94
.0	Surface of water	500
.5	Indian Fishery Shoals, 10 feet of from water, nail in root of ash tree	517.24
.5	Foot of shoals, surface of water	504
.0	Head of Indian Fishery Shoals, surface of water	516
2.5	Allens bridge, east bank, 20 feet from river, nail in root of maple tree	528.49
2.5	Surface of water	517
4.7	Lees Shoals, foot of, west bank, nail in root of ash tree	528.49
4.7	Surface of water	520
	Lees Shoals, head of, surface of water	523
6.2	Pickett Bridge, on east bank, nail in root of white oak	539.23
6.2	Surface of water	526
10.7	Flat Shoal Bridge, west bank, nail in root of white oak	551.24
10.7	Surface of water	534
13.8	Langdons Shoals, west bank, 15 feet from river, nail in root of white oak	549.69
13.8	Surface of water	539
	Langdons Shoals, head of, surface of water	543
16.9	Porterdale Shoals, foot of, 10 feet from river, west bank, nail in root of white oak	561.05
16.9	Surface of water	549
	Porterdale dam, foot of, surface of water	604
	Porterdale dam, head of, surface of water	616
17.7	Porterdale, 30 feet from dam, 20 feet from south approach, nail in root of white oak	618.38
17.7	Surface of water	616
17.7	Wagon bridge, east side of river, at extreme south end of bridge, top of steel post of railing	627.81
20.8	Browns Bridge, 60 feet above, 10 feet from river, on root of gum tree	622.81
20.8	Surface of water	611.6
22.8	Tin Bridge, on west bank river, nail in root of poplar tree	627.49
22.8	Surface of water	617
23	Georgia Railroad bridge, west side of river, on top of rock, chisel mark	642.05
23	Surface of water	617
24.3	Hendricks Bridge, north bank of river, nail in root of water oak	639.11
26	Haynes Creek, opposite mouth of, nail in root of water oak	632.26
26	Surface of water	624.6
28.2	McDaniels Bridge, west bank of river, nail in root of large water oak	644.17
28.2	Surface of water	632
	McDaniels dam, head of, surface of water	641
30.5	West side of river, Pine Log Bridge, 10 feet below, nail in root of pine	650.55
30.5	Surface of water	641

Elevations on Yellow River from mouth near Worthville to Yellow River, Ga.—Continued.

Distance in miles.		Elevation in feet.
32.2	Botosh Creek, 100 yards above mouth of, left bank of river, nail in root of pine	653.96
32.2	Surface of water	644
32.8	Foot of Milstead Shoals, west bank, nail in pine tree	657.41
32.8	Surface of water	647
33	Milstead, foot of dam, surface of water	677
33	Milstead, top of dam, surface of water	692
33	40 feet above wagon bridge, on south side of river, nail in root of large white oak	701.33
33	Surface of water	692
35.4	Irvins Bridge, 20 feet above, left bank of river, nail in root of hickory tree	697.83
35.4	Surface of water	692
36.5	Right bank, nail in root of water oak	700.62
36.5	Surface of water	694
39.4	Johnsons Bridge, east end of, top of bolt	717.53
39.4	Surface of water	702
40.2	Surface of water	705
40.3	Surface of water	707
40.8	Surface of water	709
40.9	Surface of water	711
40.9	Old dam, west side, on point in stone masonry	722.88
40.9	Surface of water	712
41.3	Foot of shoals, surface of water	714
	Head of shoals, surface of water	715
41.9	Opposite shoals, right bank, 20 feet from stream, nail in root of white oak	730.91
41.9	Surface of water	715
42.4	Mountain Creek, opposite, nail in root of white oak	727.91
42.4	Surface of water	720
43.2	Rock Bridge, on left bank, top of stone pier of	740.60
43.2	Surface of water	724
44	West bank, 10 feet from river, nail in root of ash tree	728.48
44	Surface of water	727
45.5	Opposite foot of shoals, nail in root of hickory tree	748.83
45.5	Surface of water	729
	Anniestown Shoals, foot of, surface of water	737
	Anniestown dam, foot of, surface of water	760
	Head of dam, surface of water	771
47.2	Anniestown, east bank of Haydens Branch, nail in root of large birch tree	777.64
48.6	Old mill, on large rock opposite, chisel mark	788.55

Elevations on Yellow River from mouth near Worthville to Yellow River, Ga.—Continued.

Distance in miles.		Elevation in feet.
48.6	Surface of water	772
	Head of shoals, surface of water	786
50.5	Sextons Bridge, on stone pier at, top of iron bolt	809.94
50.5	Surface of water	791
51.7	Opposite shoals, nail in root of pine	808.42
51.7	Surface of water	793
	Foot of shoals, surface of water	797
	Head of shoals, surface of water	802
53	Head of shoals, nail in root of hickory tree	818.17
53	Surface of water	804
54	Surface of water	807
55	Yellow River Bridge, left bank, nail in root of oak	825.41
55	Surface of water	815
55.7	Yellow River, east bank, 100 yardsa bove Simmons's mill, nail in root of large water oak	834.86
	Simmons's mill, below dam, surface of water	819
	Simmons's mill, head of dam, surface of water	826

ALCOVY RIVER BELOW DABNEY'S BRIDGE, GEORGIA.

In connection with this survey 17 bench marks were established and 26 water elevations were recorded. The total fall in the distance surveyed is 231 feet, but at only two points, namely, White and Factory shoals and Henderson Shoals, is the fall considerable. The remainder of the river is mostly sluggish, and tree trunks, driftwood, and other débris greatly retard the flow, so that during the rainy season the river is slow to discharge, causing the water to rise higher or spread out wider than is usually the case with rivers in this section of Georgia. The average width of the river is about 125 feet, except where shoals occur, at which points it sometimes widens to 300 feet. Very wide and low bottom lands are on each side for the first 7 miles upstream from its mouth. Then the topography suddenly changes and is much more abrupt and broken for several miles.

At the mouth of Bear Creek, which enters from the east 8 miles above the mouth of the Alcovy, is the beginning of White and Factory shoals, which form one continuous series with a fall of 83 feet in one-half mile. Here the river is in a gorge 300 feet wide, with banks over 100 feet high at several places, and midway of this shoal is an excellent site for a dam. Granite, apparently free from seams, is exposed at the surface on both sides of the river, while the river bed itself is solid rock. A dam at this point would be approxi-

mately 250 feet long. At the upper end of the shoals is another good site with the same character of bottom. A dam would have to be about 325 feet in length, and a large volume of water could be stored through the dry season, as the valley widens just above the dam site. A dam at either site would require a canal from the dam to the foot of the shoals. An old corn mill at this point uses a small wooden dam to divert the water into its flumes. Many years ago a large cotton factory stood on this site, but it was burned and never rebuilt.

Six miles above these shoals are Henderson Shoals, with a fall of 2 feet. A 6-foot dam has been erected here to supply power for a large gristmill, the back water from which extends to Dabney's bridge, 4 miles above.

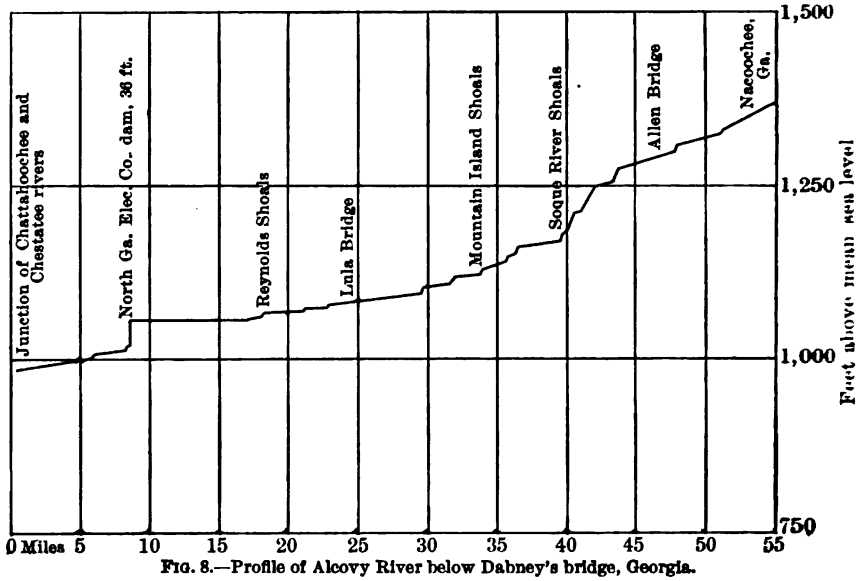


FIG. 8.—Profile of Alcovy River below Dabney's bridge, Georgia.

The construction of dams at any other points than those described would result in the sacrifice of much valuable bottom land.

The soil is very fertile, and splendid crops of cotton on the high lands and corn in the bottoms are grown on both sides of the river. With better drainage, however, a much larger amount of land could be reclaimed and made valuable for cultivation.

The elevations in the following list are based upon an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta marked "1050 M C," the elevation of which is accepted as 1,049.546 feet above mean sea level, as determined by the 1903 adjustment. The initial point of this list is a bench mark of flying levels on Ocmulgee River.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Alcovy River, from mouth, near Worthville, to Dabney's bridge, near Starrsville.

Distance in miles.		Elevation in feet.
0.0	Alcovy River, mouth of, opposite, on west bank of Ocmulgee River, nail in root of white oak	494.27
.0	Surface of water	484
1	Right bank of river, nail in root of ash tree	493.73
1	Surface of water	487
2	East bank of river, near water, nail in root of ash tree	498.40
2	Surface of water	492
3.9	Waters's bridge, spike in northeast corner	506.55
3.9	Surface of water	493
4.9	West side of river, near water, nail in root of ash tree	505.37
4.9	Surface of water	497
5.9	Left bank of river, nail in root of birch tree	505.51
5.9	Surface of water	500
6.3	Mackey Shoals, opposite foot of, on left bank, nail in root of ash tree	512.77
6.3	Mackey Shoals, foot of, surface of water	502
6.4	Mackey Shoals, head of, surface of water	504
8.2	Mackey Second Shoals, opposite foot of, left bank, nail in root of birch tree	518.50
8.2	Mackey Second Shoals, foot of, surface of water	505
	Mackey Second Shoals, head of, surface of water	508
9	Newton Factory Shoals, foot of, surface of water	509
9.2	Dam at White's mill, on Newton Factory Shoals, opposite, nail in root of black gum	562.86
9.2	Dam, foot of, surface of water	553
9.2	Dam, top of, surface of water	558
9.8	Newton Factory Bridge, on lower end of, on nut, top of bolt	592.81
9.8	Surface of water	582
10	Newton Factory Shoals, head of, surface of water	592
10.8	Left bank of river, nail in root of red-oak tree	619.86
10.8	Surface of water	593
11.5	Foot of shoals, surface of water	594
11.55	Head of shoals, surface of water	596
12.3	Left bank of river, nail in root of water oak	604.59
12.3	Surface of water	597
13	West bank, opposite shoals, nail in root of large beech tree	604.88
13	Surface of water	598
13.3	East bank river, nail in sweet-gum tree	612.85
14	Left bank river, nail in root of water oak	620.76
14	Surface of water	602
15	Henderson's bridge and mill, right bank of river, near end of bridge, nail in root of post oak	618.99
15	Surface of water	604

Elevations on Alcovy River, from mouth, near Worthville, to Dabney's bridge, near Starrsville—Continued.

Distance in miles.		Elevation in feet.
15	Henderson's mill, foot of dam, surface of water	607
15	Henderson's mill, head of dam, surface of water	613
18.3	Dabney's bridge, west side of river, near end of, nail in root of water oak (raised cut with hatchet)	627.22
18.3	Surface of water	615

TOWALIGA RIVER BELOW HIGHFALLS, GA.

Towaliga River was surveyed from its mouth, near Berner, Ga., to Highfalls, Ga., a distance of 21.7 miles. The levels are based on a line carried down South and Ocmulgee rivers from Constitution earlier in the season. The plane-table sheets were all plotted on the scale of 1:22,500. Twelve bench marks were established and 23 water-surface elevations were determined.

Towaliga River flows in a southeasterly direction and empties into Ocmulgee River. In the distance surveyed there is a fall of 194 feet, but with the exception of Highfalls there are few shoals or rapids. For 21 miles above its mouth the stream does not average more than 50 feet in width, and is very shallow. It is swift and has a clean bed.

At Highfalls there is a drop of 95 feet in a distance of 3,000 feet, in the middle of which there is a sudden drop of 42 feet, known as the Highfalls. This is an excellent dam site, for, although during the normal stage of water the volume is small, there are splendid facilities to store the water above, as the bottom is widened out into a natural basin. A flour mill has been in operation here for over one hundred years, but it uses only a trifling part of the power. It is now proposed to erect a 25-foot dam at this point to supply electric power for a railway to Indian Springs, Ga., a summer resort 8 miles from Highfalls, and also for lighting the town of Forsythe, 14 miles to the southwest. Property for 6 miles above the falls has been purchased for a storage basin. Between Highfalls and the mouth of the river there are good bottom lands, but the country is thinly settled and most of it is still in timber. The principal crops are cotton and corn.

The elevations in the following list are based upon an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta, marked "1050 M C," the elevation of which is accepted as 1,049.546 feet above mean sea level, as determined by the 1903 adjustment. The initial point of this list is a bench mark of flying levels on Ocmulgee River.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

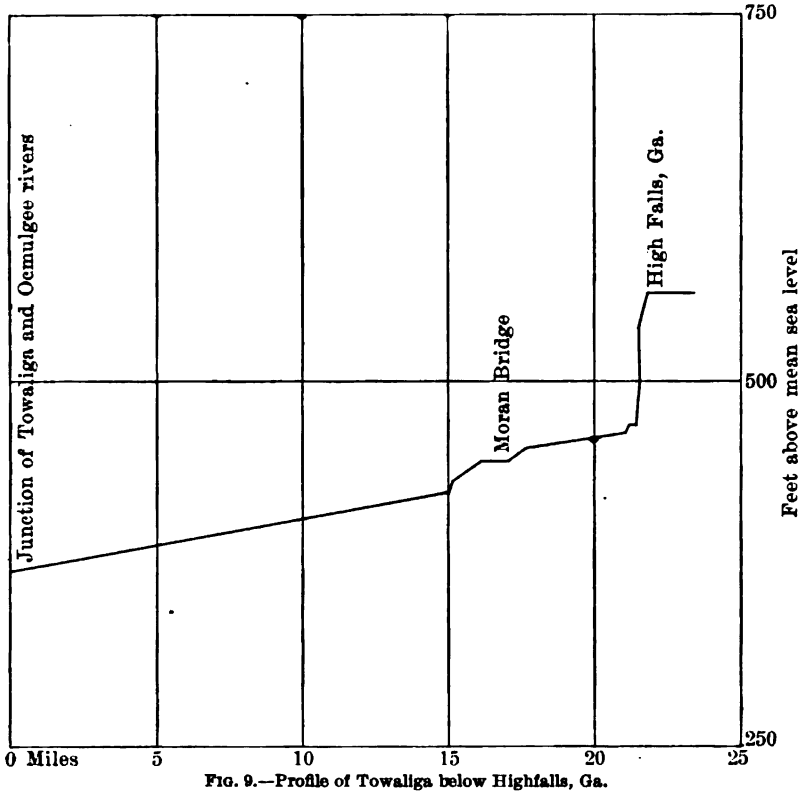


FIG. 9.—Profile of Towaliga below Highfalls, Ga.

Elevations on Towaliga River from mouth, near Berner, to Highfalls.

Distance in miles.		Elevation in feet.
0.0	Towaliga River, mouth of, on south side between railroad track and river, nail in root of water oak	379.34
.0	Surface of water	367
1.7	Lamars Bridge, near east end of, nail in root of beech tree	381.99
1.7	Surface of water	371
2.2	Small creek on west bank, mouth of, nail in root of ash tree	377.38
2.2	Surface of water	373
3.7	Surface of water	376
4	West bank, 50 feet from river, nail in root of large pine tree	412.45
4	Surface of water	379
4.6	Surface of water	382
6	Hunting Shoal Bridge, stone pier, on north end of bridge, iron bolt	412.80
6	Surface of water	386
7	North bank, 10 feet from river, twin water oak, nail in root of	399.49
7	Surface of water	393

Elevations on Towaliga River from mouth, near Berner, to Highfalls—Continued.

Distance in miles.		Elevation in feet.
8.8	Jacksons Bridge, west bank of river, large poplar tree, nail in root of	409.84
8.8	Surface of water	395
9.5	Surface of water	377
10.5	West bank of river, creek, 100 yards above mouth of, 10 feet from river, nail in root of pine tree	416.15
10.5	Surface of water	400
11.8	Wilsons Bridge, 10 feet below east approach, nail in root of water oak	421.06
11.8	Surface of water	406
12.3	West bank, on water oak	431.01
12.3	Surface of water	410
13.3	North and South forks of North Fork, 100 yards above junction of, nail in root of birch tree	416.93
13.3	Surface of water	414
14	Foot of shoals, surface of water	418
14.1	Head of shoals, surface of water	421
15	Foot of shoals, surface of water	422
15.1	Head of shoals, surface of water	428
15	Opposite shoals, north bank, nail in root of birch tree	432.23
15.5	Foot of shoals, surface of water	429
15.6	Head of shoals, surface of water	434
16	Morans Bridge, on north bank, 20 feet east of, nail in root of white oak	443.61
16	Foot of shoals, surface of water	437
16.1	Head of shoals, surface of water	439
17.4	Opposite shoals, nail in root of willow	449.74
17.4	Surface of water	443
17.5	Foot of shoals, surface of water	446
17.5	Head of shoals, surface of water	450
18	Tobes Creek, mouth of, nail in root of pine	457.48
18	Surface of water	452
18.5	Foot of shoals, surface of water	452
.0	Head of shoals, surface of water	454
18.7	Small shoals, surface of water	455
.0	Head of small shoals, surface of water	457
19.2	Branch, south bank, 20 feet above mouth of, nail in root of birch tree	462.60
21.2	Long shoals, foot of, south bank, nail in white oak tree	474.31
21.2	Surface of water	466
21.2	Highfalls Shoals, foot of, surface of water	492
21.3	Highfalls, head of Highfalls Shoals, surface of water	524
21.3	Highfalls, wagon bridge over Towiliga River, west side north approach to, top of iron bolt	563.32
21.7	Old dam, opposite, head of long shoals, surface of water	561
.0	Highfalls, high-water mark	561

CHATTAHOOCHEE RIVER FROM CHESTATEE TO SAUTEE, GA.

A survey of the upper Chattahoochee River between Chestatee and Sautee, Ga., a distance of 55 miles, was made during July and August, 1903. Between these two points a fall of 387 feet was found, the greater part of which is above the mouth of Soque River. During the survey 25 bench marks were established and 90 water-surface elevations determined. The plane-table sheets were plotted on a scale of 1:22,500. The original elevations for the levels were based upon an assumed elevation near Gainesville, Ga., but, as published herein, they have been reduced to mean sea level.

Above the mouth of Chestatee River for 10 miles are a number of small shoals aggregating a fall of 28 feet. Ten miles above the mouth of the Chestatee, Little River empties from the north, and at this point are the first good shoals, where there is a fall of 7 feet in a distance of 300 yards. A quarter of a mile above this point the North Georgia Electric Company is constructing a dam 36 feet high, which is to supply electric power. The backwater from this dam will extend 8 miles upstream, to just above Clarks Bridge. One half mile above this point is a shoal having a 9-foot fall in half a mile.

Just above this shoal are Reynolds Shoals, with a fall of 6 feet in 250 yards. There is a good power site at this point, as the banks and bottom are hard rock. From here to Mud Creek, 3 miles, there is a uniformly distributed fall of 15 feet, while just above the mouth of Mud Creek there is a good dam site. A dam here would be about 300 feet long, but the height could be 40 to 50 feet or more, if desired.

The next shoal of importance is Mountain Island Shoal. It gives a fall of 8 feet in half a mile. Here the river flows around the island between banks 100 feet high. A dam at the lower end would be 300 feet long. Perkins Shoals come next, 2 miles upstream, with a fall of 6 feet, and just above them is a shoal with a 7-foot fall. These could be used together.

From here to the mouth of Soque River is a uniform fall of 11 feet, and just above the mouth of the Soque there is a fall of 8 feet in 650 feet. For the next 3 miles there is a continuous succession of shoals, with a fall of 74 feet. The river flows in a narrow gorge of hard, unseamed rock, and at several points dams could easily be constructed. Above this point the river narrows very greatly, and is full of small shoals as far as Nacoochee Valley. From the valley to the end of the survey there are no falls or shoals.

Nacoochee Valley is very fertile and grain and grasses are raised. A large quantity of timber is still standing along the river, especially in the upper half of the valley.

The elevations in the following list are based upon an aluminum tablet at Nacoochee, marked "1349 Atlanta," in a ledge of rock 200

feet west of ford of Chattahoochee River, the elevation of which is now accepted as 1,348.269 feet above mean sea level.

The adjustment of this line was accomplished in conjunction with leveling on Chestatee and Soque rivers, tied at Willow and Clarksville, respectively, and by an extra check at Pole to primary-level circuits, and accords with the 1903 adjustment of the precise-level net.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

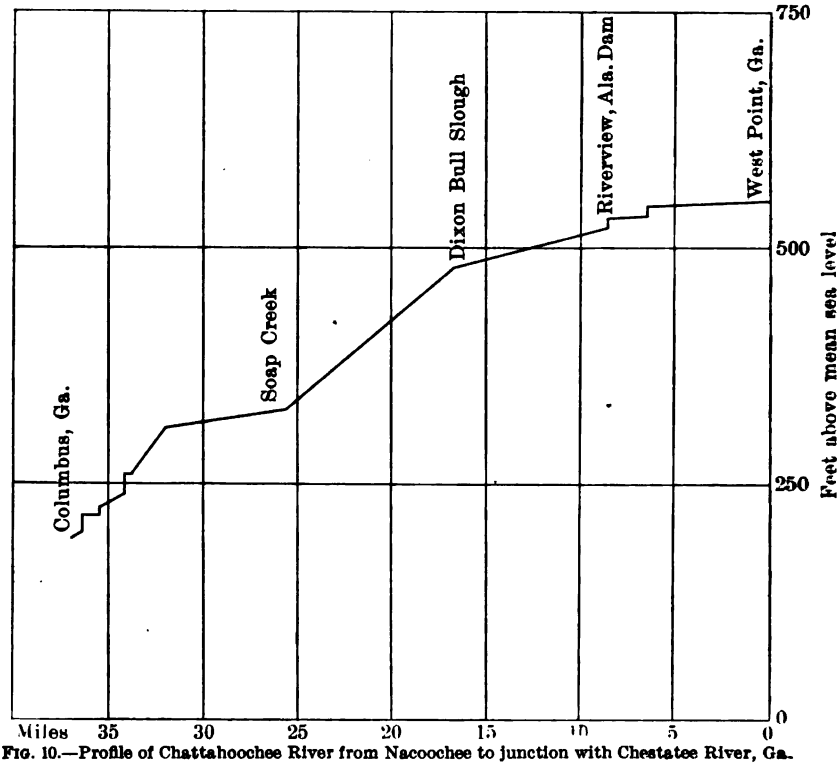


FIG. 10.—Profile of Chattahoochee River from Nacoochee to junction with Chestatee River, Ga.

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee.

Distance in miles.		Elevation in feet.
0.0	Near Keith's bridge, mouth of Chestatee River, on nail in root of walnut tree	964.37
.0	Surface of water	950
.0	Foot of shoals, surface of water	950
.0	Head of shoals, surface of water	956
1.7	On nail in root of walnut tree, north bank of river	989.71
3.7	Foot of shoals, surface of water	960
3.7	Head of shoals, surface of water	963

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee—Continued.

Distance in miles.		Elevation in feet.
5.7	Small shoals, edge of public road opposite, nail in root of large walnut tree	985.61
5.7	Small shoals, surface of water	965
6.2	Surface of water	966
6.8	Iron bridge, nail in root of large walnut tree	980.26
6.8	Surface of water	967
6.8	Foot of shoals, surface of water	967
7.3	Head of shoals, surface of water	972
8.3	Thompson Bridge, nail in root of large walnut tree	998.36
8.3	Surface of water	977
9.4	Little River, mouth of, foot of shoals, surface of water	978
9.4	Head of shoals, surface of water	984
10	North Georgia Electric Company's new dam, 100 yards below, north side of bluff, nail in root of white oak	1,004.04
10	Surface of water	985
11	Chattahoochee Park, on east side and at sharp bend of river, nail in birch tree	1,004.27
	Foot of shoals, surface of water	996
	Head of shoals, surface of water	1,010
12.2	New Bridge, near Gainesville, near small store building, large oak tree, spike in root of	1,028.32
12.2	Surface of water	1,011
13.2	South bank of river, 6 feet from water, willow tree, nail in root of	1,014.94
13.2	Surface of water	1,012
13.9	Foot of shoals, surface of water	1,012
	Head of shoals, surface of water	1,014
16.2	Clarks Bridge, east side of river, large maple tree, nail in root of	1,039.81
16.2	Surface of water	1,017
17.2	Small bluff, north side of river, poplar tree, nail in root of	1,045.27
17.2	Surface of water	1,020
	Head of shoals, surface of water	1,024
19.2	Red oak tree, nail in root of	1,043.29
19.2	Foot of shoals, surface of water	1,025
19.5	Foot of shoals, surface of water	1,028
	Head of shoals, surface of water	1,332
21.2	Savage Ferry, nail in notch of oak post	1,051.30
21.2	Surface of water	1,034
22.2	Left bank of river, nail in root of birch tree	1,050.46
22.2	Surface of water	1,037
23.9	North bank of river, nail in root of water-oak tree	1,046.76
23.9	Surface of water	1,038

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee—Continued.

Distance in miles.		Elevation in feet.
23.9	Head of shoals, surface of water	1,040
24.9	Seven Island shoals, opposite foot of, large poplar tree, nail in root of	1,066.94
	Foot of shoals, surface of water	1,040
	Head of shoals, surface of water	1,044
25.6	Flat Creek, 1 mile above mouth of, nail in root of poplar tree	1,045.84
25.6	Surface of water	1,045
26.5	Lulu bridge, 60 feet below, on north bank of river, red oak tree, nail in root of	1,065.68
26.5	Surface of water	1,049
28.8	Walnut tree in large open bottom, left bank of river, nail in root of	1,076.23
	Surface of water	1,053
29.8	Belton bridge. 100 yards below, right bank of river, walnut tree, nail in root of	1,076
29.8	Surface of water	1,056
31.8	Right bank of river, pine tree, nail in root of	1,092.99
31.8	Foot of shoals, surface of water	1,061
31.9	Head of shoals, surface of water	1,069
32.6	Nail in root of birch tree	1,085.79
32.6	Surface of water	1,070
	Foot of shoals, surface of water	1,071
	Head of shoals, surface of water	1,073
33.1	Head of shoals, on side of bluff, large pine, opposite, nail in root of	1,092.83
33.1	Surface of water	1,082
33.2	Harrisons Shoals, foot of, surface of water	1,084
34.1	Harrisons Shoals, opposite, nail in root of oak tree	1,101.70
34.1	Harrisons Shoals, surface of water	1,087
	Harrisons Shoals, head of, mouth of Mossy Creek, surface of water	1,087
34.2	Mountain Island Shoals, foot of, surface of water	1,088
	Head of shoals, surface of water	1,096
34.5	Head of shoals, opposite, nail in root of white oak	1,109.78
35.2	Foot of shoals, surface of water	1,101
35.2	Head of shoals, surface of water	1,106
35.2	Perkins Shoals, opposite foot of, nail in root of water oak	1,113.68
35.2	Perkins Shoals, foot of, surface of water	1,107
	Perkins Shoals, head of, surface of water	1,113
37.3	Foot of shoals, surface of water	1,115
	Head of shoals, surface of water	1,123
37.4	Head of shoals, north bank of river, opposite, nail in root of black-gum tree	1,127.76
38.2	Foot of shoals, surface of water	1,127
38.2	Head of shoals, surface of water	1,130

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee—Continued.

Distance in miles.		Elevation in feet.
38.3	Duncan Bridge, 30 feet below, nail in red-oak tree	1,148.90
38.4	Foot of shoals, surface of water	1,131
38.6	Head of shoals, surface of water	1,135
38.6	Head of shoals, opposite, nail in root of water oak	1,155.41
39.3	Soque River, south bank, at mouth, nail in root of birch tree	1,147.82
39.3	Surface of water	1,137
39.3	Soque River, mouth of, in forks of river, nail in root of pine stump	1,148.86
39.3	Surface of water	1,137
39.6	Head of shoals, surface of water	1,144
39.8	Foot of shoals, surface of water	1,149
40	Head of shoals, surface of water	1,159
40	Head of shoals, opposite, on west bank of river, nail in root of red oak	1,165.20
40.5	Long shoals, head of, surface of water	1,178
40.8	Foot of shoals, surface of water	1,178
	Head of shoals, surface of water	1,216
41.8	Head of shoals, root of hickory tree	1,222.10
42.3	Irwins Bridge, 10 feet below, left bank of river, nail in root of poplar tree	1,223.37
42.3	Surface of water	1,216
42.6	Irwins bridge, just above, surface of water	1,222
43.2	Head of shoals, surface of water	1,228
43.5	Foot of shoals, surface of water	1,229
	Head of shoals, surface of water	1,242
43.5	Blue Creek, surface of water	1,243
43.6	Blue Creek, 100 yards above mouth of, in fork, nail in root of red oak tree	1,256.09
44.2	Amos Ford, on west bank, large birch tree, nail in root of	1,256.09
44.2	Surface of water	1,244
44.5	Surface of water	1,247
45	Head of shoals, surface of water	1,250
46	Allens Bridge, west end of, red oak tree, nail in root of	1,266.49
46	Surface of water	1,256
	Head of shoals, surface of water	1,259
46.8	Foot of shoals, surface of water	1,260
	Head of shoals, surface of water	1,263
46.8	Head of shoals, opposite, nail in root of birch tree	1,264.18
47.3	Foot of shoals, surface of water	1,271
	Head of shoals, surface of water	1,274
47.5	Shoals, opposite head of, nail in root of pine tree	1,280.73
48.5	Foot of shoals, surface of water	1,276

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee—Continued.

Distance in miles.		Elevation in feet.
49	Head of shoals, surface of water	1,280
49	Shoals, red oak opposite head of, nail in root of	1,285.53
49	Head of shoals, surface of water	1,288
49.2	Sharp bend of river, water oak tree, nail in root of	1,304.53
49.2	Surface of water	1,292
50.5	Suspension footbridge, poplar tree at, nail in root of	1,305.97
50.5	Surface of water	1,297
51.8	Foot of shoals, surface of water	1,299
	Head of shoals, surface of water	1,306
53	Sautee Creek, near mouth of, in Nacoochee Valley, surface of water	1,309
55	Sautee Creek, ford near mouth, surface of water	1,339
55	Nacoochee post-office, 200 feet west of, ford of Chattahoochee River, 6 feet above surface of road, on ledge of rock, aluminum tablet marked "1349 Atlanta"	1,348.269

CHATTAHOOCHEE RIVER FROM CHATTAHOOCHEE TO FRANKLIN, GA.

A survey of the middle Chattahoochee River was made between Chattahoochee and Franklin, Ga., a distance of 65 miles. The elevations for this survey were based upon the United States Geological Survey bench mark at Chattahoochee, Ga., and the plane-table sheets were plotted on a scale of 1:22,500.

In the lower section of the river for 21 miles the Chattahoochee is without shoals or rapids until Redmens Shoals are reached, where there is a fall of 2 feet. The next shoals, Maderia Shoals, 11 miles farther downstream, have a fall of 6 feet in half a mile. Here, on the west side, is a large bluff of hard rock, and on the east side are flat bottom lands. The water is very shallow, and the stream has a rocky bottom. A dam here would be about 600 feet long, and to be made of sufficient height to develop any amount of head would flood valuable bottom lands above.

Below Maderia Shoals the river runs over small riffles of 1 to 2 feet until the Central of Georgia Railroad bridge is reached, and for 5 miles below this point there is practically no fall until McIntosh Shoals are reached, where there is a fall of 8 feet in a quarter of a mile. The river here runs through broken country, with high banks on both sides, showing good exposures of hard rock. A dam here would be 600 feet long, but several rocky islands would probably reduce the cost of construction. The dam could be 25 feet high or more if necessary.

Seven miles farther down the river are Fishtrap Shoals, with a 6-foot fall in a quarter of a mile. A dam here would be 700 feet long, as the west bank is low. Two miles downstream is the beginning of Bushhead Shoals, the best dam site on this section of the river. Here there is a fall of 7 feet, but added to the 5 feet just above and the 6 feet of Fishtrap Shoal, a total fall of 19 feet could be obtained in a distance of 5 miles. A dam built here would be 650 feet long and could be of any desired height. Good rock is exposed on each bank. Two flourishing towns, Newnan and Carrollton, which are about 15 miles from here, in opposite directions, would utilize this power. One mile below is a small 4-foot shoal, where the banks of the river are very flat.

At the mouth of Centralhatchee Creek, 2 miles below, is the last shoal, which has a 2-foot fall. It does not offer a good opportunity for development, owing to the low and extensive bottom lands on

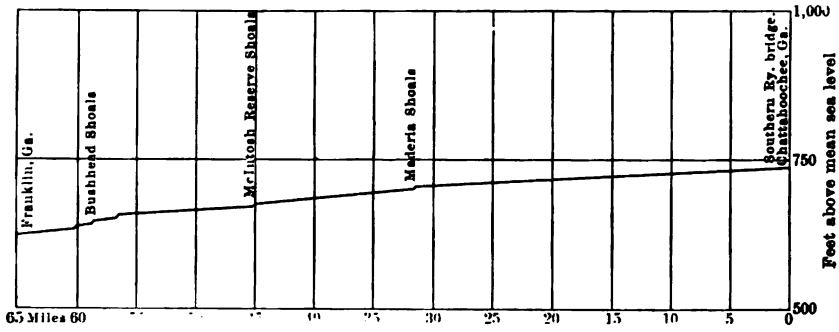


FIG. 11.—Profile of Chattahoochee River from Chattahoochee to Franklin, Ga.

the north side of the river. This section of the river has a width of about 300 feet, but in some places widens to over 1,000 feet.

Valuable and extensive bottom lands are under high cultivation, principally cotton and corn being raised, but the transportation facilities are very poor. The overflow from the river several times a year spreads a slimy sediment over the bottom which seems to act as a rich fertilizer.

For 4 miles below Chattahoochee there are valuable clay beds on the south side of the river, which have been excavated to a depth of 10 feet for brick manufacture.

The elevations in the following list are based on an aluminum tablet at the Washington street entrance to the State capitol building at Atlanta, marked "1050 M C," the elevation of which is now accepted as 1,049.546 feet above mean sea level. The line is adjusted to accord at each end, Oakdale and Franklin, with corrected primary elevations in accord with the 1903 adjustment.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Chattahoochee River from Chattahoochee to Franklin.

Distance in miles.		Elevation in feet.
0.0	Oakdale, in front of station, main track, top of south rail	809.20
.0	Surface of water	740
.5	Left bank of river, on root of willow tree	741.82
.5	Surface of water	739
1.6	Mason and Turner Ferry, near east approach to, on root to hickory tree	754.38
1.6	Surface of water	738
3.4	Old ferry, 10 feet from left bank, on root of sycamore tree	751.35
3.4	Surface of water	736
4.1	Left bank, 20 feet above bridge, on root of water oak	752.94
4.1	Surface of water	735
5.4	Left bank, 40 feet from river, on root of walnut tree	755.10
5.4	Surface of water	732
6.4	Left bank, 30 feet from river, on root of walnut tree	746.41
6.4	Surface of water	730
7.4	Left bank, 40 feet from river, on root of walnut tree	752.90
7.4	Surface of water	729
8.4	Left bank, 20 feet from river, on root of sweet gum tree	742.16
8.4	Surface of water	727
10.3	Adaholts Ferry, mouth of Sweetwater Creek, opposite, on root of large sycamore tree	744.73
10.3	Surface of water	726
11.3	Left bank, 30 feet from river, on root of large walnut tree	747.58
11.3	Surface of water	725
12.8	Dupree Ferry, left bank, 15 feet from river, on root of elm tree	738.09
12.8	Surface of water	723
14.8	Left bank, 70 feet from river, on root of walnut tree	746.29
14.8	Surface of water	721
16.6	Camp Creek, mouth of, on root of ash tree	736.13
16.6	Surface of water	720
17	Left bank, 20 feet from river, on root of walnut tree	741.78
17	Surface of water	719
17.9	Campbellton Ferry, 10 feet from river, left bank, on root of sycamore tree	728.69
17.9	Surface of water	719
20.6	Brock's ferry, 10 feet from river, left bank, on root of white oak tree	730.49
20.6	Surface of water	716
21.2	Redmens Shoals, left bank, 10 feet from river on root of sycamore tree	728.58
21.2	Surface of water	716
21.3	Redmens Shoals, foot of, surface of water	714
21.7	Pea Creek, mouth of, surface of water	714

Elevations on Chattahoochee River from Chattahoochee to Franklin—Continued.

Distance in miles.		Elevation in feet.
22	Rivertown Ferry, left bank, 10 feet from river, on root of sycamore tree	720.64
22	Surface of water	714
23.4	Pumpkintown Ferry, left bank, 15 feet from river, on large birch tree	727.94
23.4	Surface of water	712
24.5	Bear Creek, mouth of, on root of poplar tree	730.35
24.5	Surface of water	712
25.6	Left bank, 40 feet from river, on root of walnut tree	725.50
25.6	Surface of water	710
28.1	Defer's ferry, left bank, 15 feet from river, on large birch tree	722.92
28.1	Surface of water	709
29.6	Jones Ferry, left bank, 15 feet from river, on root of pine tree	718.60
29.6	Surface of water	706
30	Ballard Shoals, 10 feet from river, left bank, on root of willow tree	711.13
30.9	Ballard Shoals, head of, surface of water	705
31.1	Ballard Shoals, foot of, surface of water	704
31.4	Madeira Shoals, head of, surface of water	704
31.8	Madeira Shoals, opposite, on right bank, on root of white oak, side of rock bluff	716.81
31.8	Madeira Shoals, surface of water	702
32.1	Wolf Creek, mouth of, foot of Madeira Shoals, surface of water	698
33.4	Hutchinson's ferry, right bank, 20 feet from river, on root of maple tree	709.12
33.4	Surface of water	694
35.1	Long Island, upper end of, head of shoals, surface of water	692
35.1	Right bank, head of shoals, in root of pine tree	709.11
36	Long Island, opposite lower end of, foot of shoals, nail in root of water oak tree	703.37
36	Surface of water	689
37.5	Snake Creek, right bank, 10 feet from river, 100 yards above mouth, on root of willow tree	696.72
37.5	Surface of water	688
38.6	Moores Ferry, right bank, on root of large birch tree	702.85
38.6	Surface of water	686
39.2	Shoals, head of, surface of water	685
39.3	Shoals, foot of, surface of water	684
40.1	Central, of Georgia, Railroad bridge over river, right bank, 40 feet above bridge, on root of willow tree	692.12
40.1	Surface of water	684
40.1	Shoals, foot of, surface of water	683
40.7	Opposite right bank, nail on root of poplar tree	699.76
40.7	Surface of water	682

Elevations on Chattahoochee River from Chattahoochee to Franklin—Continued.

Distance in miles.		Elevation in feet.
41.4	Reese's ferry, right bank, on root of ash tree	693.86
41.4	Surface of water	682
41.7	Head of Shoals, surface of water	682
41.8	Foot of Shoals, surface of water	681
42.6	Fridell Shoals, head of, surface of water	680
42.7	Fridell Shoals, foot of, surface of water	679
43	Foot of bluff, right bank of river, nail in root of sweet gum tree	684.36
43.6	Hanson Shoals, head of, surface of water	678
43.9	Houston Ferry, nail in root of catalpa tree	684.02
43.9	Surface of water	677
44.9	McIntosh Reserve Shoals, head of, surface of water	676
45.4	McIntosh Reserve Shoals, foot of, right side of bank, nail in root of sweet gum tree	679.49
45.4	McIntosh Reserve Shoals, foot of, surface of water	668
46.1	Culpepper, mouth of, on root of red oak tree	678.04
46.1	Surface of water	667
49	Whooping Creek, mouth of, nail in root of birch tree	670.70
49	Surface of water	664
50	Brown's ferry, right bank, nail in root of walnut tree	661.96
50	Surface of water	662
50.7	Yellow Dirt Creek, right bank, nail in root of sweet gum tree	679.80
50.7	Surface of water	662
50.9	Yellow Dirt Creek, mouth of, surface of water	660
53.1	Hollingsworth Ferry, right bank, nail in root of water oak tree	673.31
53.1	Surface of water	658
55	Pink Creek, mouth of, surface of water	658
55.3	Right bank, on nail in root of sweet gum tree	664.97
55.3	Surface of water	658
56.3	Fishtrap Shoals, head of, surface of water	657
56.9	Fishtrap Shoals, right bank, opposite center of shoals, elm tree, nail in root of	670.26
56.9	Fishtrap Shoals, surface of water	652
57.5	Fishtrap Shoals, foot of, surface of water	648
58.5	Bushhead Shoals, opposite upper island, nail in root of birch	653.32
58.5	Bushhead Shoals, head of, surface of water	645
59	Bushhead Shoals, foot of, on side of bluff, nail in root of white oak	648.15
59	Bushhead Shoals, foot of, surface of water	638
60	Head of shoals, surface of water	638
60.2	Foot of shoals, surface of water	634
60.8	Head of shoals, surface of water	634
61	Foot of shoals, surface of water	632
62	Head of shoals, surface of water	632

Elevations on Chattahoochee River from Chattahoochee to Franklin—Continued.

Distance in miles		Elevation in feet.
62.2	Foot of shoals, surface of water	628
63.8	Centralhatchee Creek, opposite mouth of, nail in root of birch	633.49
63.8	Surface of water	628
64	Foot of shoals, surface of water	627
64.5	Franklin, wagon bridge, surface of water	626
64.7	Franklin, on rivet on top left iron pier of east approach of wagon bridge	655.17
65	Franklin, in south side of court-house, bronze tablet marked "695 A"	694.742

CHATTAHOOCHEE RIVER FROM WEST POINT TO COLUMBUS, GA.

Chattahoochee River was surveyed from West Point to Columbus, Ga., a distance of 37 miles, in which there is a fall of 361 feet. During the work 5 bench marks were established and 35 water-surface elevations obtained. The survey was plotted on the scale of 1: 22,500, and was accompanied by a flying-level line based on a United States Geological Survey tablet at West Point, Ga.

For 4 miles below West Point the river is sluggish. At Langdale, Ala., there is a wing dam with 9 feet head, operating a knitting mill. The dam is loosely built of light lumber, connecting a number of small islands, and a large amount of water goes to waste.

Probably the best site for a permanent structure at Langdale is about one-half mile below the present mill, where a head of 18 feet would back water to just below West Point. A dam as proposed above would not, except in time of flood, spread the backwater beyond the present banks of the river.

Between Langdale and Riverview, where there is another knitting mill, there is a continuous network of small islands. At Riverview there is a 9-foot wing dam similar to that at Langdale, but it furnishes even less water, as the eastern channel is broader.

From Riverview to Columbus the river is one continuous shoal, and the choice of sites for dam construction rests on minor details rather than amount of power.

Some of the best sites are just below Houstons Ferry, 3¼ miles from Riverview, where a 24-foot dam would have good ledge-rock foundations for the 480 feet of river bed, while the ordinary red clay of the region appears on the banks.

Three miles farther downstream, about 1 mile below Blantons Ferry, is another site, but a dam here would flood a good deal of

bottom land. For 4 miles below here is one of the swiftest and roughest parts of the river. There is a good site at the end of the stretch, just below the Big Bull Slough, and another one-third of a mile above Bartlett's old ferry. The former could probably be developed into a valuable plant, supplying power to West Point, Lanett, Hamilton, Opelika, and a score of smaller towns, all less than 25 miles from this point. A dam probably could be built here with a head of 70 feet. The river bottom is ledge rock, with some bowlders, and the shores are of the same rock covered with more or less soil. A dam 70 feet high would back the water nearly to Mountain Oak Creek. Many of the islands in the river would be flooded. Some of them are large and cultivated to some extent. There would also be some flooding of bottom lands on both sides of the river, but no lands of pronounced value would be destroyed.

About 5¾ miles farther downstream, at what is known locally as Goats Rock, a dam very similar to the above could be constructed. The shore lines are very precipitous and ledge rock outcrops on both banks. A head of 70 feet would utilize all the available power between this point and the proposed dam 5¾ miles above.

Seven and one-half miles below is the beginning of what is known as the old Clapp factory falls. This is one of the best rapids on the river. Unfortunately, the river is exceptionally wide and the construction of a dam would be expensive. The old mill derived its power by means of a wing dam which has not been used upward of fifteen years. A dam here, backing the water up to Goat Rock, and a canal carrying it to the foot of the falls, will give a total head of about 77 feet. The river bottom is ledge rock, and the shores are the same covered with several feet of soil.

One and one-fourth miles below the old Clapp factory is the dam of the Columbus Power Company. This dam has a head of 32 feet, developed by a stone concrete dam, below which the tailrace has been deepened and separated from the river by a stone wall. Part of the power is utilized by the large cotton mill of the company, situated on the east bank of the river. The balance is distributed about the city of Columbus.

One and one-fourth miles farther down the stream is what is called the city mill dam, with 9½ feet head. It is a wooden structure and needs constant attention, furnishing power to the city of Columbus and to a gristmill. Three-fourths of a mile below is a stone dam kept in good repair and owned by the Eagle and Phoenix Company, one of the largest cotton manufacturing companies in the South. Just below this dam is the head of navigation for steamboats.

The elevations in the following list are based upon a bronze tablet in west abutment of Altanta and West Point Railroad bridge over Chattahoochee River at West Point. The elevation of this, as

determined by a net of primary levels, extended from Rome, Ga., a point on the precise-level net, is 573.193 feet above mean sea level, in accord with the 1903 corrected elevation of that place.

The leveling was done under the direction of I. T. Fitch, field assistant, by W. H. Sallee, levelman.

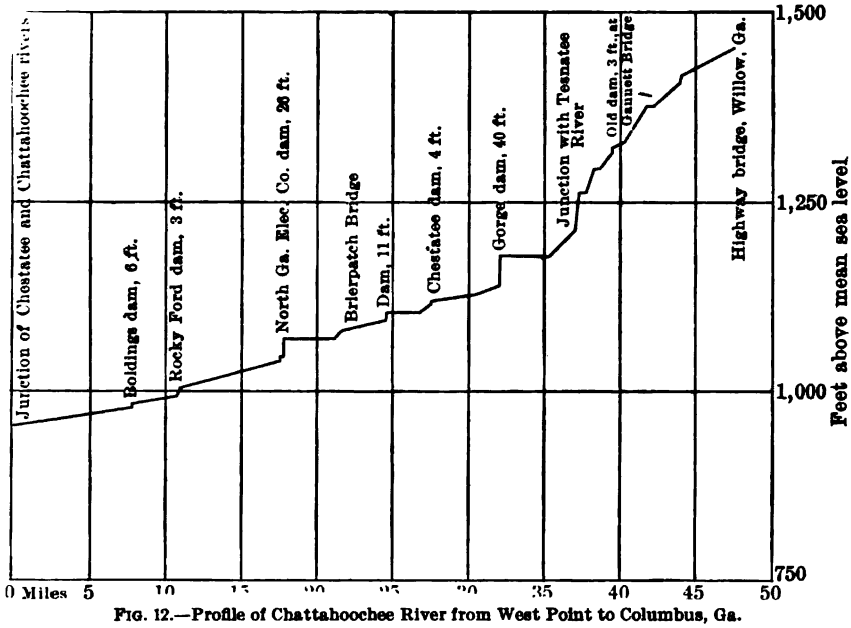


FIG. 12.—Profile of Chattahoochee River from West Point to Columbus, Ga.

Elevations on Chattahoochee River from West Point to Columbus, Ga. (single spur line)

Distance in miles.		Elevation in feet.
0.0	West Point, in west abutment of Atlanta and West Point Railroad bridge over Chattahoochee River, bronze tablet marked "573 A"	573.193
.0	Highway bridge, surface of water	551
.0	Tidewater elevation corresponding to zero of local hydrographic station	549
.0	West Point, opposite, in Alabama, United States engineers' bench mark, 1,000 feet north of highway bridge, 100 feet east of road intersection, west bank of river, 75 feet from water, iron monument sunk in ground	564.28
3.1	Long Cane Creek, surface of water	549
6	Langdale, Ala., 90 feet south of Moores Creek, in factory lawn between factory and track, top of hydrant	548.54
6	Langdale, mill pond at, surface of water	542.1
6	Langdale, below dam, surface of water	533
8.6	Riverview, mill pond, surface of water	532
8.6	Riverview, below mill pond, surface of water	522
8.6	Riverview, opposite, in Alabama, northwest corner of cotton mill, 35 feet southwest of, 50 feet south of dam, top of double-orifice hydrant	534.94

Elevations on Chattahoochee River from West Point to Columbus, Ga. (single spur line)—Continued.

Distance in miles.		Elevation in feet.
12	Houstons Ferry, surface of water	497
14.4	Blantons Ferry, west side of river, 200 feet from edge of water, 25 feet east of poplar tree, wagon road, top of knob, south side of blazed tree	508.74
16.6	Dixons Ferry, surface of water	483
20.3	Bartletts old ferry, 50 feet northwest of west bank of river, top of ledge, rock 18 feet from water	404.78
23.7	Mulberry Creek, Georgia, surface of water	363
34.7	Columbus Power Company, mill pond, surface of water	260
34.7	Columbus Power Company, below pond, surface of water	240
35.9	Columbus, mill pond of city milldam, surface of water	226
	Columbus, below mill pond of city milldam, surface of water	216
36.1	Columbus, above Eagle and Phoenix Company dam, surface of water	216
36.1	Columbus, below Eagle and Phoenix Company dam, surface of water	200
37	Columbus, beneath highway covered bridge, surface of water	190
37	Girard, Ala., Broad and Sixth streets, southeast corner of intersection, bucket and windlass well, 45 feet east of, top of stone guard post at Wm. C. Bill's saloon	255.14

SOQUE RIVER BELOW CLARKSVILLE, GA.

Soque River was surveyed from its mouth, near View, Ga., to Clarksville, Ga., a distance of 8 miles. The levels were based on a line carried up Chattahoochee River from Gainesville, Ga., and the field sheets were platted on the scale of 1:22,500.

The first power is 5½ miles above its mouth and 1 mile below from Bert. Here there is an undeveloped fall of 6 feet in about 50 yards. The south bank is hard rock; the north bank is not very high, but seems to be solid rock. The best site for a dam is probably at the lower end of the falls. A dam here would be about 380 feet long and not over 7 feet high, or the water would back up over the lower end of more valuable shoals above.

At Bert, Ga., are the Porter Shoals, which have a drop of 48 feet—far the best waterfall on the river. A small wing dam develops power to operate Porter's woolen and cotton factory, 4 miles from Demorest, Ga., the nearest railroad point.

About 500 feet upstream is Porter's upper shoal, at which there is a 15-foot fall partly developed by a small dam, and which supplies power for factory No. 2 of the same company. A much greater head would be obtained here by increasing the size of the dam.

One and one-half miles above Bert is a splendid water-power site, known as the Old Factory Shoals, where there is a fall of 23 feet in a distance of 600 feet. There was a dam here at one time, but all

signs of it have vanished. The river is about 350 feet wide and flows in several channels between small islands. Good sandstone outcrops on both banks.

Just above this point the river bottoms widen and the farming lands are better between here and Clarksville, the end of the survey, than any point on the river.

The elevations in the following list are based upon an aluminum tablet at the north side of east entrance to the court-house at Clarksville, marked "1372 Atlanta," the elevation of which is accepted as 1,371.991 feet above mean sea level, in accord with the 1903 adjustment of the precise-level net.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

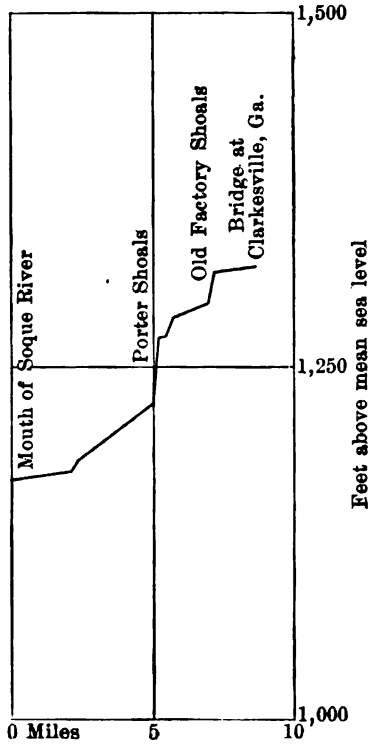


FIG. 13.—Profile of Soque River below Clarksville, Ga

Elevations on Soque River from near View to Clarksville, Ga.

Distance in miles.		Elevation in feet.
0.0	Soque River, south bank of mouth of, at junction of Soque and Chattahoochee rivers, birch tree, nail in root of	1,147.82
.0	Surface of water	1,137
1.6	McAllisters Bridge, near north end of, nail in root of white oak	1,156.30

Elevations on Soque River from near View to Clarkesville, Ga.—Continued.

Distance in miles.		Elevation in feet.
1.6	Surface of water	1,142
	Foot of shoals, surface of water	1,142
	Head of shoals, surface of water	1,149
4	Newbridge, hickory tree on north bank, nail in root	1,171.71
	Surface of water	1,152
4.1	Foot of shoals, surface of water	1,153
	Head of shoals, surface of water	1,156
4.7	Foot of shoals, surface of water	1,156
	Head of shoals, surface of water	1,162
5.6	Foot of shoals, surface of water	1,166
5.7	Head of shoals, surface of water	1,181
6.1	Porter's mills, foot of Porter Shoals, surface of water	1,189
6.1	Bert, head of Porter Shoals, surface of water	1,237
5.9	Bert, Porter Shoals, opposite head of shoals, water oak, nail in root of	1,189.07
6.1	Bert, near north end of wagon bridge, red oak tree, nail in root of	1,246.13
6.2	Bert, foot of upper shoals, surface of water	1,238
	Head of upper shoals, surface of water	1,253
6.3	Bert, Ga., 200 yards above factory, near river, on root of water oak	1,262.75
7.3	Foot of shoals, surface of water	1,261
7.3	Left bank of river, nail on root of sycamore tree	1,287.37
7.3	Surface of water, head of shoals	1,284
8.8	Clarksville, Habersham County court-house, on north side of east entrance, aluminum tablet marked "1372 Atlanta"	1,371.991
8.8	Surface of water	1,289

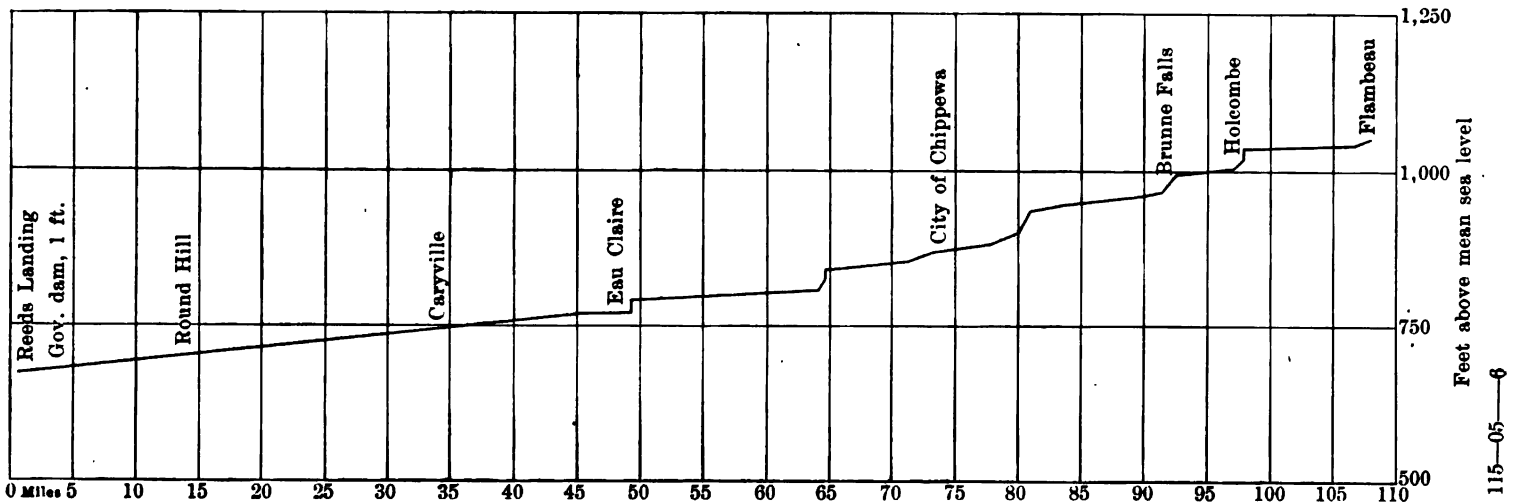
CHESTATEE RIVER BELOW WILLOW, GA.

Chestatee River was surveyed from Willow, Ga., to its mouth, near Chestatee, a distance of 47.7 miles.

A line of secondary levels was run, based on a primary bench mark of the United States Geological Survey, 2 miles north of Willow. The field sheets were platted on the scale of 1:22,500. During the course of the survey 40 bench marks were established and 98 water-surface elevations obtained.

For the first 8 miles the river traverses a very wild and broken country, and is only about 50 feet wide. There is not enough water to produce any considerable amount of power, although there is a fall of 124 feet.

At Gannett Bridge there is an old 3-foot dam which was used to furnish power for a gold-stamping mill, the machinery of which is now



PROFILE OF CHESTATEE RIVER BELOW WILLOW, GA.

ruined from disuse. This is about the north boundary of the Dahlonega gold field now under vigorous development.

One mile downstream is an unnamed shoal, with a fall of 30 feet in 0.6 of a mile. The river runs between very steep banks of hard, unseamed rocks, and a 200-foot dam could be constructed here, abundant material being easily accessible.

Just below Grinnells Ford is a splendid site, where the river suddenly drops 47 feet in about 150 yards and passes through a narrow gorge. The river bed is of broken rock, and a dam at this point would be about 200 feet long.

About 2 miles farther down is a drop of 11 feet in 100 yards. The river runs through a narrow gorge, but just above the valley widens enough to make a good storage basin. A dam would be about 225 feet long and could be built to almost any desired height. A pyrites mine here employs 50 men. Four miles below the Crown Gold Mining Company is erecting a 40-foot dam, known as the Gorge dam, to run hydraulic pumps for two placer mines.. This dam will back up the water for 2½ miles and will cover a number of small shoals.

The river below here runs swiftly, but without important shoals for about 3½ miles. It then enters the back water from Chestatee dam, which is 4 feet high, and supplies power for a gristmill, cotton gin, and hydraulic pump.

Three miles farther down is a gold-stamping mill, the power for which is supplied by an 11-foot dam, which backs the water up as far as Iron Bridge just below the Chestatee dam. Six miles farther down is a 26-foot dam, built by the North Georgia Electric Company, at Newbridge, Ga., which supplies power for the traction system and lighting of the city of Gainesville, Ga., 15 miles away. A smaller dam, 4 feet high, just below the main structure, furnishes power for a gristmill and cotton gin.

Below Newbridge, Ga., the river enters a more level country and runs with little fall to Bolden's bridge, 9 miles below, passing a 3-foot dam, which is used to operate a small flouring mill, and a 6-foot dam, which supplies power for a large gristmill.

In the remaining 8 miles there are no shoals or opportunities for power development. The sand in the bed of the river contains a large amount of gold, and placer mining on a considerable scale is one of the occupations of the people throughout this whole region.

Nearly all of the important shoals which are undeveloped are controlled by the mining interests in the neighborhood. The upper part of the survey was through fairly heavy timber, but the lower end of the work was through land all under high cultivation. The river passes 3 miles from Dahlonega, the county seat of Lumpkin County.

The elevations in the following list are based upon a bronze tablet 2.5 miles north of Willow, in rock on west side of river at fork of

road, marked "1529 Atlanta," the elevation of which is accepted as 1,528.649 feet above mean sea level, in accord with the 1903 adjustment of the precise-level net.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Chestatee River below Willow, Ga.

Distance in miles.		Elevation in feet.
2.5	Willow, 2.5 miles north of, on west side of river, at fork of road, in rock, bronze tablet marked "1529 Atlanta"	1,528.649
.0	Willow, near west end of bridge, walnut tree, nail in root of	1,461.37
.0	Surface of water	1,454
.25	Surface of water	1,449
1	Foot of shoals, opposite, west side of river, nail in root of maple tree	1,447.54
1	Head of shoals, surface of water	1,446
	Foot of shoals, surface of water	1,444
1.6	Head of shoals, surface of water	1,443
	Foot of shoals, surface of water	1,438
2.5	Head of shoals, surface of water	1,428
2.7	Foot of shoals, surface of water	1,422
3	Right bank and 10 feet from river, nail in root of red oak tree	1,437.94
3	Surface of water	1,416
3.7	Head of large shoals, surface of water	1,415.5
3.8	Foot of large shoals, surface of water	1,406
4	Shoals, opposite, right bank of river, nail in root of red oak	1,425.41
4	Surface of water	1,405
4.2	Foot of shoals, surface of water	1,399
4.7	Sharp bend of river, right bank, nail in root of red oak	1,404.53
4.7	Surface of water	1,394
4.9	Crooked Shoal, head of, surface of water	1,390
5.2	Crooked Shoal, foot of, surface of water	1,386
5.2	Head of shoals, surface of water	1,384
5.4	Foot of shoals, surface of water	1,378
5.4	Left bank of river, opposite shoals, large white oak, nail in foot of	1,388.79
6	Head of shoals, surface of water	1,377
6.4	Foot of shoals, surface of water	1,353
6.4	Foot of shoals, left bank, 60 feet below, nail in root of hickory	1,364.25
6.9	Head of shoals, surface of water	1,346
	Foot of shoals, surface of water	1,328
7.3	Small creek, mouth of, opposite center of shoals, spruce pine, nail in root of	1,335.59
8	Old dam, top of, surface of water	1,321
	Old dam, bottom of, surface of water	1,317
8.2	Gannett Bridge, 10 feet below, on left bank river, nail in red oak	1,318.35

Elevations on Chestatee River below Willow, Ga.—Continued.

Distance in miles.		Elevation in feet.
8.2	Surface of water	1,309
8.5	Old gold-stamping mill, foot of bridge at, surface of water	1,305
8.8	Head of shoals, surface of water	1,304
	Foot of shoals, surface of water	1,296
	Foot of shoals, opposite, left bank river, nail in root of sweet gum tree	1,303.10
9.4	Head of shoals, surface of water	1,293
9.9	Grinnells Ford, foot of shoals, surface of water	1,263
10	Grinnells Ford, in root of large birch tree, near ford, nail in root of	1,265.45
10.3	Head of shoals, surface of water	1,262
10.7	Tesnatee River, mouth of, foot of shoals, surface of water	1,215
10.7	Tesnatee River, mouth of, in fork between rivers, on side of rock bluff, in white oak tree, nail	1,231.37
11.1	Grinnell's lower ford, surface of water	1,209
11.2	Grinnell's lower ford, on right bank 100 yards below ford, point of large rock, chisel mark	1,218.11
11.2	Grinnell's lower ford, foot of shoals, surface of water	1,207
11.4	Head of shoals, surface of water	1,206
11.6	Foot of shoals, surface of water	1,201
11.6	Right bank of river, nail in root of hickory tree	1,214.34
11.7	Head of shoals, surface of water	1,200
11.9	Foot of shoals, surface of water	1,189
12.6	Head of shoals, surface of water	1,187
	Foot of shoals, surface of water	1,174
12.8	Right bank river, pine tree, nail in root of	1,183.54
13.5	Head of shoals, surface of water	1,169
	Foot of shoals, surface of water	1,163
14	White oak tree, nail in root of	1,166.95
14	Surface of water	1,160
14.6	Head of shoals, surface of water	1,155
	Foot of shoals, surface of water	1,150
14.9	Gorge dam, above, head of shoals, surface of water	1,149
15.8	Gorge dam, 40 feet below, right bank of river, nail in hickory tree	1,159.21
15.9	Gorge dam, below dam, foot of shoals, surface of water	1,138
16.4	Surface of water	1,133
17	Bearden's bridge, top of stone pier on west approach, iron bolt	1,150.10
17	Surface of water	1,130
17.6	Head of shoals, surface of water	1,125
17.8	Surface of water	1,122
20.2	Chestatee dam, top of, surface of water	1,119
20.2	Chestatee dam, foot of, surface of water	1,115
20.4	Iron Bridge, 60 feet below, beech tree, nail in root of	1,121.86

road, marked "1529 Atlanta," the elevation of which is accepted as 1,528.649 feet above mean sea level, in accord with the 1903 adjustment of the precise-level net.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Chestatee River below Willow, Ga.

Distance in miles.		Elevation in feet.
2.5	Willow, 2.5 miles north of, on west side of river, at fork of road, in rock, bronze tablet marked "1529 Atlanta"	1,528.649
.0	Willow, near west end of bridge, walnut tree, nail in root of	1,461.37
.0	Surface of water	1,454
.25	Surface of water	1,449
1	Foot of shoals, opposite, west side of river, nail in root of maple tree	1,447.54
1	Head of shoals, surface of water	1,446
	Foot of shoals, surface of water	1,444
1.6	Head of shoals, surface of water	1,443
	Foot of shoals, surface of water	1,438
2.5	Head of shoals, surface of water	1,428
2.7	Foot of shoals, surface of water	1,422
3	Right bank and 10 feet from river, nail in root of red oak tree	1,437.94
3	Surface of water	1,416
3.7	Head of large shoals, surface of water	1,415.5
3.8	Foot of large shoals, surface of water	1,406
4	Shoals, opposite, right bank of river, nail in root of red oak	1,425.41
4	Surface of water	1,405
4.2	Foot of shoals, surface of water	1,399
4.7	Sharp bend of river, right bank, nail in root of red oak	1,404.53
4.7	Surface of water	1,394
4.9	Crooked Shoal, head of, surface of water	1,390
5.2	Crooked Shoal, foot of, surface of water	1,386
5.2	Head of shoals, surface of water	1,384
5.4	Foot of shoals, surface of water	1,378
5.4	Left bank of river, opposite shoals, large white oak, nail in foot of	1,388.79
6	Head of shoals, surface of water	1,377
6.4	Foot of shoals, surface of water	1,353
6.4	Foot of shoals, left bank, 60 feet below, nail in root of hickory	[illegible]
6.9	Head of shoals, surface of water	[illegible]
	Foot of shoals, surface of water	[illegible]
7.3	Small creek, mouth of, oppos[illegible] in root of	[illegible]
8	Old dam, top of, surface	[illegible]
	Old dam, bottom of,	[illegible]
8.2	Gannett Bridge, 10	[illegible]

Elevations on Chestatee River below Willow, Ga.—Continued.

Distance in miles.		Elevation in feet.
39.8	Bolden's bridge, west side of east approach, top of, iron bolt	1,001.28
39.8	Surface of water	984
39.9	Mill, top of dam, surface of water	983
	Mill, foot of dam, surface of water	977
40.8	Langleys Creek, east side, 40 feet below mouth, nail in root of red oak	989.34
40.8	Langleys Creek, mouth of, surface of water	972
40.9	Surface of water	970
42.6	East bank of river, nail in root of sycamore tree	974.48
42.6	Surface of water	964
43.4	Surface of water	963
44.6	River, 200 feet from, in open field, nail in walnut tree	975.87
44.6	Surface of water	960
45.6	Mouth of branch, near, 40 feet from east bank of river, nail in red oak tree	981.76
47.7	Chestatee, Ga., near, at mouth of Chestatee River, near Keith's bridge, nail in root of walnut tree	964.37

HIWASSEE RIVER FROM HIWASSEE, GA., TO APALACHIA, N. C.

Hiwassee River was surveyed from Hiwassee, Ga., to Apalachia, N. C., a distance of 63 miles. In that distance there is a fall of 707 feet. A line of secondary levels based on the United States Geological Survey bench mark at Hiwassee, Ga., was run. The field sheets were plotted on the scale of 1:22,500. During the course of the survey 39 bench marks were established and 119 water-surface elevations obtained.

There are no shoals of any consequence until just below Bell Creek, where there is one of 10 feet with good rock bottom and rock bluffs on the northeast side of the river. A dam could be constructed here with a length of about 200 feet.

One mile below Hayesville Bridge is a shoal with a fall of 18 feet in 1¼ miles, but no suitable place for a dam was noted.

One and one-half miles below, at Passmore Ford, is a shoal with a 21-foot fall in 1¼ miles and with a fairly good site for the construction of a dam. The bottom is rocky and there are rock bluffs on the south side of the river. The dam would be about 300 feet long.

Four and one-half miles below is the 12-foot dam of the Cherokee Lumber Company. This is a splendid site. A 40-foot structure would not back the water over 1½ miles and would not do any damage to cultivated lands.

Three miles below, at Island Ford, is a shoal with a 17-foot fall in

road, marked "1529 Atlanta," the elevation of which is accepted as 1,528.649 feet above mean sea level, in accord with the 1903 adjustment of the precise-level net.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Chestatee River below Willow, Ga.

Distance in miles.		Elevation in feet.
2.5	Willow, 2.5 miles north of, on west side of river, at fork of road, in rock, bronze tablet marked "1529 Atlanta"	1,528.649
.0	Willow, near west end of bridge, walnut tree, nail in root of	1,461.37
.0	Surface of water	1,454
.25	Surface of water	1,449
1	Foot of shoals, opposite, west side of river, nail in root of maple tree	1,447.54
1	Head of shoals, surface of water	1,446
	Foot of shoals, surface of water	1,444
1.6	Head of shoals, surface of water	1,443
	Foot of shoals, surface of water	1,438
2.5	Head of shoals, surface of water	1,428
2.7	Foot of shoals, surface of water	1,422
3	Right bank and 10 feet from river, nail in root of red oak tree	1,437.94
3	Surface of water	1,416
3.7	Head of large shoals, surface of water	1,415.5
3.8	Foot of large shoals, surface of water	1,406
4	Shoals, opposite, right bank of river, nail in root of red oak	1,425.41
4	Surface of water	1,405
4.2	Foot of shoals, surface of water	1,399
4.7	Sharp bend of river, right bank, nail in root of red oak	1,404.53
4.7	Surface of water	1,394
4.9	Crooked Shoal, head of, surface of water	1,390
5.2	Crooked Shoal, foot of, surface of water	1,386
5.2	Head of shoals, surface of water	1,384
5.4	Foot of shoals, surface of water	1,378
5.4	Left bank of river, opposite shoals, large white oak, nail in foot of	1,388.79
6	Head of shoals, surface of water	1,377
6.4	Foot of shoals, surface of water	1,353
6.4	Foot of shoals, left bank, 60 feet below, nail in root of hickory	1,364.25
6.9	Head of shoals, surface of water	1,346
	Foot of shoals, surface of water	1,328
7.3	Small creek, mouth of, opposite center of shoals, spruce pine, nail in root of	1,335.59
8	Old dam, top of, surface of water	1,321
	Old dam, bottom of, surface of water	1,317
8.2	Gannett Bridge, 10 feet below, on left bank river, nail in red oak	1,318.35

Elevations on Chestatee River below Willow, Ga.—Continued.

Distance in miles.		Elevation in feet.
8.2	Surface of water	1,309
8.5	Old gold-stamping mill, foot of bridge at, surface of water	1,305
8.8	Head of shoals, surface of water	1,304
	Foot of shoals, surface of water	1,296
	Foot of shoals, opposite, left bank river, nail in root of sweet gum tree	1,303.10
9.4	Head of shoals, surface of water	1,293
9.9	Grinnells Ford, foot of shoals, surface of water	1,263
10	Grinnells Ford, in root of large birch tree, near ford, nail in root of	1,265.45
10.3	Head of shoals, surface of water	1,262
10.7	Tesnatee River, mouth of, foot of shoals, surface of water	1,215
10.7	Tesnatee River, mouth of, in fork between rivers, on side of rock bluff, in white oak tree, nail	1,231.37
11.1	Grinnell's lower ford, surface of water	1,209
11.2	Grinnell's lower ford, on right bank 100 yards below ford, point of large rock, chisel mark	1,218.11
11.2	Grinnell's lower ford, foot of shoals, surface of water	1,207
11.4	Head of shoals, surface of water	1,206
11.6	Foot of shoals, surface of water	1,201
11.6	Right bank of river, nail in root of hickory tree	1,214.34
11.7	Head of shoals, surface of water	1,200
11.9	Foot of shoals, surface of water	1,189
12.6	Head of shoals, surface of water	1,187
	Foot of shoals, surface of water	1,174
12.8	Right bank river, pine tree, nail in root of	1,183.54
13.5	Head of shoals, surface of water	1,169
	Foot of shoals, surface of water	1,163
14	White oak tree, nail in root of	1,166.95
14	Surface of water	1,160
14.6	Head of shoals, surface of water	1,155
	Foot of shoals, surface of water	1,150
14.9	Gorge dam, above, head of shoals, surface of water	1,149
15.8	Gorge dam, 40 feet below, right bank of river, nail in hickory tree	1,159.21
15.9	Gorge dam, below dam, foot of shoals, surface of water	1,138
16.4	Surface of water	1,133
17	Bearden's bridge, top of stone pier on west approach, iron bolt	1,150.10
17	Surface of water	1,130
17.6	Head of shoals, surface of water	1,125
17.8	Surface of water	1,122
20.2	Chestatee dam, top of, surface of water	1,119
20.2	Chestatee dam, foot of, surface of water	1,115
20.4	Iron Bridge, 60 feet below, beech tree, nail in root of	1,121.86

road, marked "1529 Atlanta," the elevation of which is accepted as 1,528.649 feet above mean sea level, in accord with the 1903 adjustment of the precise-level net.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Chestatee River below Willow, Ga.

Distance in miles.		Elevation in feet.
2.5	Willow, 2.5 miles north of, on west side of river, at fork of road, in rock, bronze tablet marked "1529 Atlanta"	1,528.649
.0	Willow, near west end of bridge, walnut tree, nail in root of	1,461.37
.0	Surface of water	1,454
.25	Surface of water	1,449
1	Foot of shoals, opposite, west side of river, nail in root of maple tree	1,447.54
1	Head of shoals, surface of water	1,446
	Foot of shoals, surface of water	1,444
1.6	Head of shoals, surface of water	1,443
	Foot of shoals, surface of water	1,438
2.5	Head of shoals, surface of water	1,428
2.7	Foot of shoals, surface of water	1,422
3	Right bank and 10 feet from river, nail in root of red oak tree	1,437.94
3	Surface of water	1,416
3.7	Head of large shoals, surface of water	1,415.5
3.8	Foot of large shoals, surface of water	1,406
4	Shoals, opposite, right bank of river, nail in root of red oak	1,425.41
4	Surface of water	1,405
4.2	Foot of shoals, surface of water	1,399
4.7	Sharp bend of river, right bank, nail in root of red oak	1,404.53
4.7	Surface of water	1,394
4.9	Crooked Shoal, head of, surface of water	1,390
5.2	Crooked Shoal, foot of, surface of water	1,386
5.2	Head of shoals, surface of water	1,384
5.4	Foot of shoals, surface of water	1,378
5.4	Left bank of river, opposite shoals, large white oak, nail in foot of	1,388.79
6	Head of shoals, surface of water	1,377
6.4	Foot of shoals, surface of water	1,353
6.4	Foot of shoals, left bank, 60 feet below, nail in root of hickory	1,364.25
6.9	Head of shoals, surface of water	1,346
	Foot of shoals, surface of water	1,328
7.3	Small creek, mouth of, opposite center of shoals, spruce pine, nail in root of	1,335.59
8	Old dam, top of, surface of water	1,321
	Old dam, bottom of, surface of water	1,317
8.2	Gannett Bridge, 10 feet below, on left bank river, nail in red oak	1,318.35

Elevations on Chestatee River below Willow, Ga.—Continued.

Distance in miles.		Elevation in feet.
8.2	Surface of water	1,309
8.5	Old gold-stamping mill, foot of bridge at, surface of water	1,305
8.8	Head of shoals, surface of water	1,304
	Foot of shoals, surface of water	1,296
	Foot of shoals, opposite, left bank river, nail in root of sweet gum tree	1,303.10
9.4	Head of shoals, surface of water	1,293
9.9	Grinnells Ford, foot of shoals, surface of water	1,263
10	Grinnells Ford, in root of large birch tree, near ford, nail in root of	1,265.45
10.3	Head of shoals, surface of water	1,262
10.7	Tesnatee River, mouth of, foot of shoals, surface of water	1,215
10.7	Tesnatee River, mouth of, in fork between rivers, on side of rock bluff, in white oak tree, nail	1,231.37
11.1	Grinnell's lower ford, surface of water	1,209
11.2	Grinnell's lower ford, on right bank 100 yards below ford, point of large rock, chisel mark	1,218.11
11.2	Grinnell's lower ford, foot of shoals, surface of water	1,207
11.4	Head of shoals, surface of water	1,206
11.6	Foot of shoals, surface of water	1,201
11.6	Right bank of river, nail in root of hickory tree	1,214.34
11.7	Head of shoals, surface of water	1,200
11.9	Foot of shoals, surface of water	1,189
12.6	Head of shoals, surface of water	1,187
	Foot of shoals, surface of water	1,174
12.8	Right bank river, pine tree, nail in root of	1,183.54
13.5	Head of shoals, surface of water	1,169
	Foot of shoals, surface of water	1,163
14	White oak tree, nail in root of	1,166.95
14	Surface of water	1,160
14.6	Head of shoals, surface of water	1,155
	Foot of shoals, surface of water	1,150
14.9	Gorge dam, above, head of shoals, surface of water	1,149
15.8	Gorge dam, 40 feet below, right bank of river, nail in hickory tree	1,159.21
15.9	Gorge dam, below dam, foot of shoals, surface of water	1,138
16.4	Surface of water	1,133
17	Bearden's bridge, top of stone pier on west approach, iron bolt	1,150.10
17	Surface of water	1,130
17.6	Head of shoals, surface of water	1,125
17.8	Surface of water	1,122
20.2	Chestatee dam, top of, surface of water	1,119
20.2	Chestatee dam, foot of, surface of water	1,115
20.4	Iron Bridge, 60 feet below, beech tree, nail in root of	1,121.86

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The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Chestatee River below Willow, Ga.

Distance in miles.		Elevation in feet.
2.5	Willow, 2.5 miles north of, on west side of river, at fork of road, in rock, bronze tablet marked "1529 Atlanta"	1,528.649
.0	Willow, near west end of bridge, walnut tree, nail in root of	1,461.37
.0	Surface of water	1,454
.25	Surface of water	1,449
1	Foot of shoals, opposite, west side of river, nail in root of maple tree	1,447.54
1	Head of shoals, surface of water	1,446
	Foot of shoals, surface of water	1,444
1.6	Head of shoals, surface of water	1,443
	Foot of shoals, surface of water	1,438
2.5	Head of shoals, surface of water	1,428
2.7	Foot of shoals, surface of water	1,422
3	Right bank and 10 feet from river, nail in root of red oak tree	1,437.94
3	Surface of water	1,416
3.7	Head of large shoals, surface of water	1,415.5
3.8	Foot of large shoals, surface of water	1,406
4	Shoals, opposite, right bank of river, nail in root of red oak	1,425.41
4	Surface of water	1,405
4.2	Foot of shoals, surface of water	1,399
4.7	Sharp bend of river, right bank, nail in root of red oak	1,404.53
4.7	Surface of water	1,394
4.9	Crooked Shoal, head of, surface of water	1,390
5.2	Crooked Shoal, foot of, surface of water	1,386
5.2	Head of shoals, surface of water	1,384
5.4	Foot of shoals, surface of water	1,378
5.4	Left bank of river, opposite shoals, large white oak, nail in foot of	1,388.79
6	Head of shoals, surface of water	1,377
6.4	Foot of shoals, surface of water	1,353
6.4	Foot of shoals, left bank, 60 feet below, nail in root of hickory	1,364.25
6.9	Head of shoals, surface of water	1,346
	Foot of shoals, surface of water	1,328
7.3	Small creek, mouth of, opposite center of shoals, spruce pine, nail in root of	1,335.59
8	Old dam, top of, surface of water	1,321
	Old dam, bottom of, surface of water	1,317
8.2	Gannett Bridge, 10 feet below, on left bank river, nail in red oak	1,318.35

Elevations on Chestatee River below Willow, Ga.—Continued.

Distance in miles.		Elevation in feet.
8.2	Surface of water	1,309
8.5	Old gold-stamping mill, foot of bridge at, surface of water	1,305
8.8	Head of shoals, surface of water	1,304
	Foot of shoals, surface of water	1,296
	Foot of shoals, opposite, left bank river, nail in root of sweet gum tree	1,303.10
9.4	Head of shoals, surface of water	1,293
9.9	Grinnells Ford, foot of shoals, surface of water	1,263
10	Grinnells Ford, in root of large birch tree, near ford, nail in root of	1,265.45
10.3	Head of shoals, surface of water	1,262
10.7	Tesnatee River, mouth of, foot of shoals, surface of water	1,215
10.7	Tesnatee River, mouth of, in fork between rivers, on side of rock bluff, in white oak tree, nail	1,231.37
11.1	Grinnell's lower ford, surface of water	1,209
11.2	Grinnell's lower ford, on right bank 100 yards below ford, point of large rock, chisel mark	1,218.11
11.2	Grinnell's lower ford, foot of shoals, surface of water	1,207
11.4	Head of shoals, surface of water	1,206
11.6	Foot of shoals, surface of water	1,201
11.6	Right bank of river, nail in root of hickory tree	1,214.34
11.7	Head of shoals, surface of water	1,200
11.9	Foot of shoals, surface of water	1,189
12.6	Head of shoals, surface of water	1,187
	Foot of shoals, surface of water	1,174
12.8	Right bank river, pine tree, nail in root of	1,183.54
13.5	Head of shoals, surface of water	1,169
	Foot of shoals, surface of water	1,163
14	White oak tree, nail in root of	1,166.95
14	Surface of water	1,160
14.6	Head of shoals, surface of water	1,155
	Foot of shoals, surface of water	1,150
14.9	Gorge dam, above, head of shoals, surface of water	1,149
15.8	Gorge dam, 40 feet below, right bank of river, nail in hickory tree	1,159.21
15.9	Gorge dam, below dam, foot of shoals, surface of water	1,138
16.4	Surface of water	1,133
17	Bearden's bridge, top of stone pier on west approach, iron bolt	1,150.10
17	Surface of water	1,130
17.6	Head of shoals, surface of water	1,125
17.8	Surface of water	1,122
20.2	Chestatee dam, top of, surface of water	1,119
20.2	Chestatee dam, foot of, surface of water	1,115
20.4	Iron Bridge, 60 feet below, beech tree, nail in root of	1,121.86

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Elevations on Chestatee River below Willow, Ga.

Distance in miles.		Elevation in feet.
2.5	Willow, 2.5 miles north of, on west side of river, at fork of road, in rock, bronze tablet marked "1529 Atlanta"	1,528.649
.0	Willow, near west end of bridge, walnut tree, nail in root of	1,461.37
.0	Surface of water	1,454
.25	Surface of water	1,449
1	Foot of shoals, opposite, west side of river, nail in root of maple tree	1,447.54
1	Head of shoals, surface of water	1,446
	Foot of shoals, surface of water	1,444
1.6	Head of shoals, surface of water	1,443
	Foot of shoals, surface of water	1,438
2.5	Head of shoals, surface of water	1,428
2.7	Foot of shoals, surface of water	1,422
3	Right bank and 10 feet from river, nail in root of red oak tree	1,437.94
3	Surface of water	1,416
3.7	Head of large shoals, surface of water	1,415.5
3.8	Foot of large shoals, surface of water	1,406
4	Shoals, opposite, right bank of river, nail in root of red oak	1,425.41
4	Surface of water	1,405
4.2	Foot of shoals, surface of water	1,399
4.7	Sharp bend of river, right bank, nail in root of red oak	1,404.53
4.7	Surface of water	1,394
4.9	Crooked Shoal, head of, surface of water	1,390
5.2	Crooked Shoal, foot of, surface of water	1,386
5.2	Head of shoals, surface of water	1,384
5.4	Foot of shoals, surface of water	1,378
5.4	Left bank of river, opposite shoals, large white oak, nail in foot of	1,388.79
6	Head of shoals, surface of water	1,377
6.4	Foot of shoals, surface of water	1,353
6.4	Foot of shoals, left bank, 60 feet below, nail in root of hickory	1,364.25
6.9	Head of shoals, surface of water	1,346
	Foot of shoals, surface of water	1,328
7.3	Small creek, mouth of, opposite center of shoals, spruce pine, nail in root of	1,335.59
8	Old dam, top of, surface of water	1,321
	Old dam, bottom of, surface of water	1,317
8.2	Gannett Bridge, 10 feet below, on left bank river, nail in red oak	1,318.35

Elevations on Chestatee River below Willow, Ga.—Continued.

Distance in miles.		Elevation in feet.
8.2	Surface of water	1,309
8.5	Old gold-stamping mill, foot of bridge at, surface of water	1,305
8.8	Head of shoals, surface of water	1,304
	Foot of shoals, surface of water	1,296
	Foot of shoals, opposite, left bank river, nail in root of sweet gum tree	1,303.10
9.4	Head of shoals, surface of water	1,293
9.9	Grinnells Ford, foot of shoals, surface of water	1,263
10	Grinnells Ford, in root of large birch tree, near ford, nail in root of	1,265.45
10.3	Head of shoals, surface of water	1,262
10.7	Tesnatee River, mouth of, foot of shoals, surface of water	1,215
10.7	Tesnatee River, mouth of, in fork between rivers, on side of rock bluff, in white oak tree, nail	1,231.37
11.1	Grinnell's lower ford, surface of water	1,209
11.2	Grinnell's lower ford, on right bank 100 yards below ford, point of large rock, chisel mark	1,218.11
11.2	Grinnell's lower ford, foot of shoals, surface of water	1,207
11.4	Head of shoals, surface of water	1,206
11.6	Foot of shoals, surface of water	1,201
11.6	Right bank of river, nail in root of hickory tree	1,214.34
11.7	Head of shoals, surface of water	1,200
11.9	Foot of shoals, surface of water	1,189
12.6	Head of shoals, surface of water	1,187
	Foot of shoals, surface of water	1,174
12.8	Right bank river, pine tree, nail in root of	1,183.54
13.5	Head of shoals, surface of water	1,169
	Foot of shoals, surface of water	1,163
14	White oak tree, nail in root of	1,166.95
14	Surface of water	1,160
14.6	Head of shoals, surface of water	1,155
	Foot of shoals, surface of water	1,150
14.9	Gorge dam, above, head of shoals, surface of water	1,149
15.8	Gorge dam, 40 feet below, right bank of river, nail in hickory tree	1,159.21
15.9	Gorge dam, below dam, foot of shoals, surface of water	1,138
16.4	Surface of water	1,133
17	Bearden's bridge, top of stone pier on west approach, iron bolt	1,150.10
17	Surface of water	1,130
17.6	Head of shoals, surface of water	1,125
17.8	Surface of water	1,122
20.2	Chestatee dam, top of, surface of water	1,119
20.2	Chestatee dam, foot of, surface of water	1,115
20.4	Iron Bridge, 60 feet below, beech tree, nail in root of	1,121.86

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Elevations on Chestatee River below Willow, Ga.

Distance in miles.		Elevation in feet.
2.5	Willow, 2.5 miles north of, on west side of river, at fork of road, in rock, bronze tablet marked "1529 Atlanta"	1,528.649
.0	Willow, near west end of bridge, walnut tree, nail in root of	1,461.37
.0	Surface of water	1,454
.25	Surface of water	1,449
1	Foot of shoals, opposite, west side of river, nail in root of maple tree	1,447.54
1	Head of shoals, surface of water	1,446
	Foot of shoals, surface of water	1,444
1.6	Head of shoals, surface of water	1,443
	Foot of shoals, surface of water	1,438
2.5	Head of shoals, surface of water	1,428
2.7	Foot of shoals, surface of water	1,422
3	Right bank and 10 feet from river, nail in root of red oak tree	1,437.94
3	Surface of water	1,416
3.7	Head of large shoals, surface of water	1,415.5
3.8	Foot of large shoals, surface of water	1,406
4	Shoals, opposite, right bank of river, nail in root of red oak	1,425.41
4	Surface of water	1,405
4.2	Foot of shoals, surface of water	1,399
4.7	Sharp bend of river, right bank, nail in root of red oak	1,404.53
4.7	Surface of water	1,394
4.9	Crooked Shoal, head of, surface of water	1,390
5.2	Crooked Shoal, foot of, surface of water	1,386
5.2	Head of shoals, surface of water	1,384
5.4	Foot of shoals, surface of water	1,378
5.4	Left bank of river, opposite shoals, large white oak, nail in foot of	1,388.79
6	Head of shoals, surface of water	1,377
6.4	Foot of shoals, surface of water	1,353
6.4	Foot of shoals, left bank, 60 feet below, nail in root of hickory	1,364.25
6.9	Head of shoals, surface of water	1,346
	Foot of shoals, surface of water	1,328
7.3	Small creek, mouth of, opposite center of shoals, spruce pine, nail in root of	1,335.59
8	Old dam, top of, surface of water	1,321
	Old dam, bottom of, surface of water	1,317
8.2	Gannett Bridge, 10 feet below, on left bank river, nail in red oak	1,318.35

Elevations on Chestatee River below Willow, Ga.—Continued.

Distance in miles.		Elevation in feet.
8.2	Surface of water	1,309
8.5	Old gold-stamping mill, foot of bridge at, surface of water	1,305
8.8	Head of shoals, surface of water	1,304
	Foot of shoals, surface of water	1,296
	Foot of shoals, opposite, left bank river, nail in root of sweet gum tree	1,303.10
9.4	Head of shoals, surface of water	1,293
9.9	Grinnells Ford, foot of shoals, surface of water	1,263
10	Grinnells Ford, in root of large birch tree, near ford, nail in root of	1,265.45
10.3	Head of shoals, surface of water	1,262
10.7	Tesnatee River, mouth of, foot of shoals, surface of water	1,215
10.7	Tesnatee River, mouth of, in fork between rivers, on side of rock bluff, in white oak tree, nail	1,231.37
11.1	Grinnell's lower ford, surface of water	1,209
11.2	Grinnell's lower ford, on right bank 100 yards below ford, point of large rock, chisel mark	1,218.11
11.2	Grinnell's lower ford, foot of shoals, surface of water	1,207
11.4	Head of shoals, surface of water	1,206
11.6	Foot of shoals, surface of water	1,201
11.6	Right bank of river, nail in root of hickory tree	1,214.34
11.7	Head of shoals, surface of water	1,200
11.9	Foot of shoals, surface of water	1,189
12.6	Head of shoals, surface of water	1,187
	Foot of shoals, surface of water	1,174
12.8	Right bank river, pine tree, nail in root of	1,183.54
13.5	Head of shoals, surface of water	1,169
	Foot of shoals, surface of water	1,163
14	White oak tree, nail in root of	1,166.95
14	Surface of water	1,160
14.6	Head of shoals, surface of water	1,155
	Foot of shoals, surface of water	1,150
14.9	Gorge dam, above, head of shoals, surface of water	1,149
15.8	Gorge dam, 40 feet below, right bank of river, nail in hickory tree	1,159.21
15.9	Gorge dam, below dam, foot of shoals, surface of water	1,138
16.4	Surface of water	1,133
17	Bearden's bridge, top of stone pier on west approach, iron bolt	1,150.10
17	Surface of water	1,130
17.6	Head of shoals, surface of water	1,125
17.8	Surface of water	1,122
20.2	Chestatee dam, top of, surface of water	1,119
20.2	Chestatee dam, foot of, surface of water	1,115
20.4	Iron Bridge, 60 feet below, beech tree, nail in root of	1,121.86

Elevations on Nottely River from its mouth to Blairsville, Ga.—Continued.

Distance in miles.		Elevation in feet.
27.9	Above shoals, surface of water	1,698
28.4	Morgan Ford, 40 feet north of, red-oak tree	1,714
28.4	Surface of water	1,702
29	Mouth of Young Cane Creek, surface of water	1,699
29	Mouth of Castile Creek, surface of water	1,709
29.1	Castile Creek, 1,600 feet above, on rock, edge of river, point on rock	1,714.20
29.4	Above rapids, surface of water	1,715
30	Above fish dam, surface of water	1,718
30.3	McBee Ford, 60 feet north of, nail in side of red oak	1,734.37
30.3	Surface of water	1,721
30.8	Above branch, surface of water	1,723
31.1	Mouth of Reece Creek, surface of water	1,724
31.4	Youngs Ford, 80 feet southwest of, red-oak tree	1,741.02
31.4	Surface of water	1,727
31.5	Millburn Creek, just below, surface of water	1,730
31.9	At canal, surface of water at foot of	1,732
31.9	Head of canal, surface of water	1,735
31.9	Canal cut, 50 feet northeast of river, 15 feet southwest of ford, nail in root of red-oak tree (cut has a drop of 3.6 feet)	1,741.26
32.2	Above small rapids, surface of water	1,739
33	Mouth of creek, surface of water	1,743
33.6	Watkins Bridge, 375 feet above, north edge of river, point on rock	1,747.54
33.6	Surface of water	1,747
33.6	Jarrett milldam, foot of, surface of water	1,748
33.6	Jarrett milldam, head of, surface of water (Jarrett milldam has a drop of 3.79 feet)	1,752
34.5	Reeds Ford, 150 feet east of, nail in root of walnut tree	1,766.24
34.5	Surface of water	1,755
35	Above small rapids, surface of water	1,760
35.9	Blairsville Bridge, 100 feet southeast of, mouth of Butternut Creek, 15 feet north of, nail in side of red-oak tree	1,775.94
35.9	Surface of water	1,769
35.9	High water	1,783
37.2	Blairsville court-house, Union County, Ga., in wall on west side of building, bronze tablet	1,891.59

TOCCOA RIVER BELOW DIAL, GA.

Toccoa River was surveyed from Butts Bridge, 3 miles east of Dial Ga., to the Tennessee State line, near McCays, Tenn. In the 36 miles surveyed there is a fall of 414 feet. A line of secondary levels was run based on the primary bench mark of the United States Geological

Survey, three-fourths of a mile northeast of Butts Bridge. The field sheets were plotted on the scale of 1:22,500, and during the course of this survey 27 bench marks were established and 94 water-surface elevations were obtained.

Toccoa River flows in a northwesterly direction, and after crossing the Tennessee State line is known as Ocoee River. Between Pigeon Creek and Dial Bridge there is a shoal, with a fall of 21 feet in 1¼ miles. There are good foundations for a dam 250 feet long.

From upper Big Creek to Shallow Ford, 3 miles, there is a fall of 55 feet in an almost continuous shoal. There are several available power sites, and building material is easily accessible. From Shallow Ford

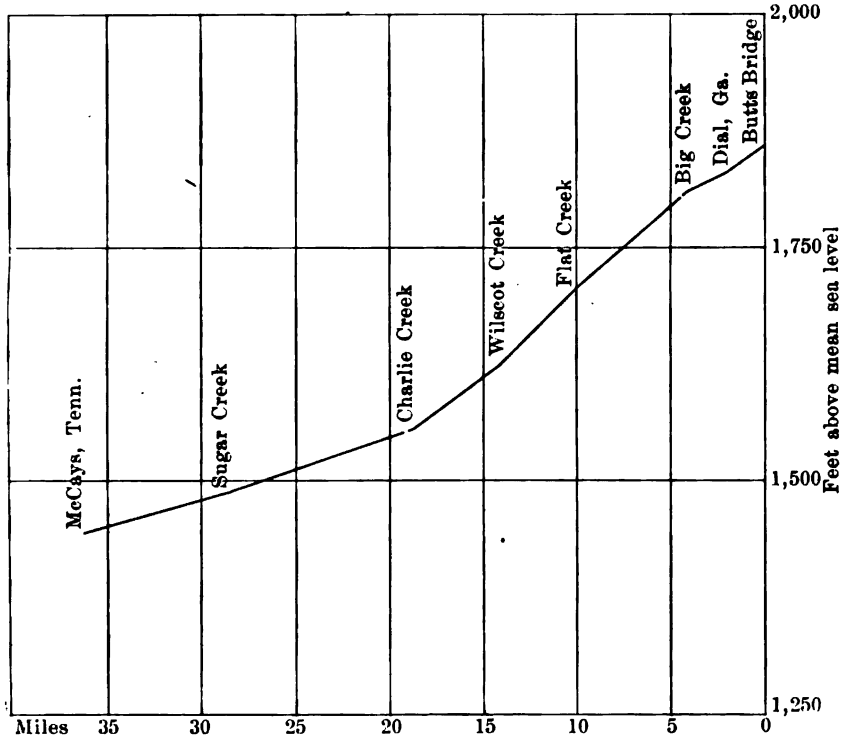

FIG. 16.—Profile of Toccoa River below Dial, Ga.

to Wilscot Creek, 7½ miles, the river has an average fall of 18 feet per mile. There are several excellent sites where there is hard rock on either side.

From Wilscot Creek to Charlie Creek there is an average fall of 14 feet per mile, with several fine shoals having steep hills and good hard bottom.

Eleven miles down the river, at Galloway, Ga., there is a shoal with a fall of 10 feet in half a mile. This would be a good site for a small dam. From one-half mile below Galloway to McCays, Tenn., 6 miles, the river has a fall of 60 feet, with several good power sites.

The elevations in the following list are based upon an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta, marked "1050 M C," the elevation of which is now accepted as 1,049.546 feet above mean sea level. They accord with the 1903 adjusted elevations of primary bench marks near Morganton and Shallow Ford. The section from Shallow Ford to McCays Ferry is a single spur line.

The leveling was done under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

Elevations on Toccoa River from Butts Bridge, Georgia, to Tennessee State line.

Distance in miles.		Elevation in feet.
0.0	Morganton (3 miles east of Dial), forks of Morganton and Ellijay road, in large marble rock, copper bolt marked "1981"	1,947.821
1.5	Butts Bridge, surface of water	1,858
1.5	Butts Bridge, east side of, nail in top of abutment	1,874.25
1.5	High-water mark	1,870
2	Pigeon Creek, 550 feet east of, north side of road, 60 feet north of river, point on rock	1,858.35
2	Mouth of Pigeon Creek, surface of water	1,849
2.3	Between rapids, surface of water	1,845
2.5	Foot of shoals, surface of water	1,840
2.9	Mouth of Weeks Creek, foot of rapids, surface of water	1,830
3.1	Dial post-office, Van Zant's bridge, 100 feet north of, east side of road, nail in root of red-oak tree	1,844.68
3.1	Surface of water	1,828
3.1	High-water mark	1,851
4	Mouth of Noontootly Creek, surface of water	1,823
4	Mouth of branch, surface of water	1,821
4.2	Rogers Ford, 50 feet west of, nail in root of tree	1,825.14
4.2	Surface of water	1,820
4.7	Surface of water	1,815
5.1	In rapids, surface of water	1,813
5.2	Big Creek Ford, 225 feet southeast of, 50 feet south of river, nail in root of white-oak tree	1,817.74
5.2	Surface of water	1,810
5.2	In rapids, surface of water	1,809
5.7	Above rapids, surface of water	1,802
5.9	Below fish dam, surface of water	1,799
6.1	Head of shoals, surface of water	1,795
6.4	Foot of shoals, surface of water	1,791
6.4	Surface of water	1,790
7	Surface of water	1,782
7.1	Shallow Ford, 1 mile north of, north side of road, in large rock, copper bolt marked "1859"	1,826.439

Elevations on Toccoa River from Butts Bridge, Georgia, to Tennessee State line—Continued.

Distance in miles.		Elevation in feet.
	Single flying level spur line to McCays Ferry.	
7.1	Below rapids, surface of water	1,779
7.6	In rapids, surface of water	1,769
8.1	Shallow Ford, 100 feet north of, nail in root of red-oak tree	1,774.93
8.1	Surface of water	1,763
8.1	High-water mark	1,774
8.3	In rapids, surface of water	1,758
8.6	Surface of water	1,755
8.8	Mouth of Stanley Creek, surface of water	1,752
9.1	Rapids, surface of water	1,747
9.3	Mouth of stream, surface of water	1,743
9.5	Below rapids, surface of water	1,738
9.9	Stanley Creek, 1 mile northwest of, opposite island, north side of river, point on rock	1,738.77
10	In rapids, surface of water	1,729
10.2	Opposite falls in river, 50 feet north of first falls, point on large rock	1,744.02
10.2	Head of falls, surface of water	1,728
10.2	Foot of falls, surface of water	1,719
10.7	Mouth of branch, surface of water	1,717
11	Below rapids, surface of water	1,709
11.2	Mouth of Flat Creek, surface of water	1,705
11.5	In rapids, surface of water	1,691
11.6	Surface of water	1,690
11.8	Head of long shoals, surface of water	1,689
11.8	Rock cliff, south side of river, opposite large shoals, point in side of	1,692.11
11.9	Head of island, in shoals, surface of water	1,679
12	Foot of island, in shoals, surface of water	1,677
12.9	In shoals, surface of water	1,665
13.3	Foot of large shoals, surface of water	1,659
13.4	Below rapids, head of more shoals, surface of water	1,656
13.4	In rapids, surface of water	1,646
14	Foot of shoals, surface of water	1,640
14.6	Mouth of Persimmon Creek, surface of water	1,633
14.6	Persimmon Creek, 300 feet east of, west side of river, nail in root of large dead stump	1,638.06
14.7	Below fish dam, surface of water	1,629
15.2	Mouth of stream, surface of water	1,624
15.4	Mouth of Wilscot Creek, surface of water	1,624
15.8	In shoals, surface of water	1,616
16	Foot of shoals, surface of water	1,609
16.8	In rapids, surface of water	1,602

Elevations on Toccoa River from Butts Bridge, Georgia, to Tennessee State line—Continued.

Distance in miles.		Elevation in feet.
	Single flying level spur line to McCays Ferry—Continued.	
8	Wilscot Creek, 1.5 miles northwest of, rock cliff, 18 feet north of river, point on very large rock	1,608.96
16.9	In shoals, surface of water	1,600
17.1	Foot of shoals, surface of water	1,596
17.3	Tarpley Ford, surface of water	1,593
17.3	Tarpley Ford, 20 feet west of, nail in root of beech tree	1,598.30
17.6	In rapids, surface of water	1,589
18.2	Mouth of creek, surface of water	1,576
18.3	Surface of water	1,571
18.8	Mouth of creek, surface of water	1,568
19	Mouth of Bullfrog Creek, surface of water	1,565
19.6	Surface of water	1,559
20	Mouth of Charlie Creek, surface of water	1,555
20	Lovingood Ford, 300 feet northeast of, nail in side of walnut tree	1,564.61
20	Surface of water	1,554
20	High-water mark	1,569
21.5	Mouth of Star Creek, surface of water	1,550
21.6	Below fish dam, surface of water	1,548
22	Mouth of Rogers Branch, surface of water	1,547
22.4	Toccoa Bridge, surface of water	1,546
22.4	Toccoa Bridge, 10 feet east of, nail in root of beech tree	1,557.64
22.9	Mouth of spring stream, surface of water	1,540
23.5	Below small rapids, surface of water	1,539
23.6	Mouth of Weavers Creek, surface of water	1,538
23.9	At Benchlog Ford, surface of water	1,538
23.9	Benchlog Ford, 20 feet northeast of, nail in side of beech tree	1,543.47
25.2	Large bend in river, surface of water	1,528
25.5	Atlanta, Knoxville and Northern Railroad bridge, east side of bridge abutment, point on rock	1,536.79
25.5	Surface of water	1,526
25.5	High-water mark	1,541
26.6	Mouth of branch, surface of water	1,519
26.8	Harts Ford, 100 feet west of, stump on edge of bank at canoe landing, nail in side of	1,521.90
26.8	Surface of water	1,516
28	Surface of water	1,510
28.8	Bakers Ford, 100 feet southeast of, on edge of bank, nail in side of birch tree	1,515
28.8	Surface of water	1,507
29.6	Surface of water	1,504
30	Bend of river, surface of water	1,502

Elevations on Toccoa River from Butts Bridge, Georgia, to Tennessee State line—Continued.

Distance in miles.		Elevation in feet.
	Single flying level spur line to McCays Ferry—Continued.	
30.2	Surface of water	1,498
30.9	Mouth of Sugar Creek, surface of water	1,494
30.9	Sugar Creek railroad bridge abutment, point in center of east side of bridge	1,508.32
31.2	Below Galloway Ford, surface of water	1,592
31.5	In shoals, surface of water	1,589
32.1	200 feet northwest of ford, 4 feet southeast of Atlanta, Knoxville and Northern Railroad track, nail in side of peach tree	1,562.69
32.1	Surface of water	1,484
32.5	Canoe Landing, surface of water	1,479
32.8	Hothouse Creek, mouth of, surface of water	1,476
33.7	Foot of small shoals, near island, surface of water	1,467
34	Mouth of Barker Creek, surface of water	1,464
34.5	Kyle post-office, 600 feet east of, Atlanta, Knoxville and Northern Railroad bridge over Barker Creek, on southeast end of, end bolt	1,482.43
34.6	Kyle post-office, 40 feet south of, in front of Queen Brothers' store, pile supporting platform, nail in top of	1,483.62
34.6	Kyle ford, surface of water	1,463
35	Below rapids, surface of water	1,458
35.4	Mouth of Wolf Creek, surface of water	1,455
35.8	Atlanta, Knoxville and Northern Railroad bridge over Ocoee River, east side of bridge, point on abutment	1,471.98
35.8	Surface of water	1,452
36.1	In bend of river, surface of water	1,450
36.3	Dillbeck Ford, north edge of river, nail in side of dead birch tree	1,451.87
36.3	Surface of water	1,447
37.5	McCays post-office, Polk County, Tenn., rock supporting southwest corner of, point on	1,468.07
37.5	McCays Ferry, north side of river, pile supporting swinging bridge, cartridge shell in top of	1,460.15
37.5	High-water mark	1,469
37.5	Surface of water	1,444

CHIPPEWA RIVER FROM REEDS LANDING, MINNESOTA, TO FLAMBEAU, WIS.

Between April 15 and June 12, 1903, J. R. Ellis, field assistant, ran a careful double-rodded primary-level line along the Chippewa River from Reeds Landing, Minnesota, to Chippewa Falls, Wis. This work was under the general direction of J. H. Renshawe, geographer in charge of the central section of topography. Later in the year it was decided to continue this work above Chippewa Falls, and on

September 1 the central and eastern sections having united as the eastern section of topography, H. M. Wilson, geographer in charge, assigned F. T. Fitch, field assistant, to this work. Between that date and October 4 Mr. Fitch ran a line of flying levels accompanied by a plane-table stadia traverse and topographic sketching from Chippewa Falls to Flambeau, Wis.

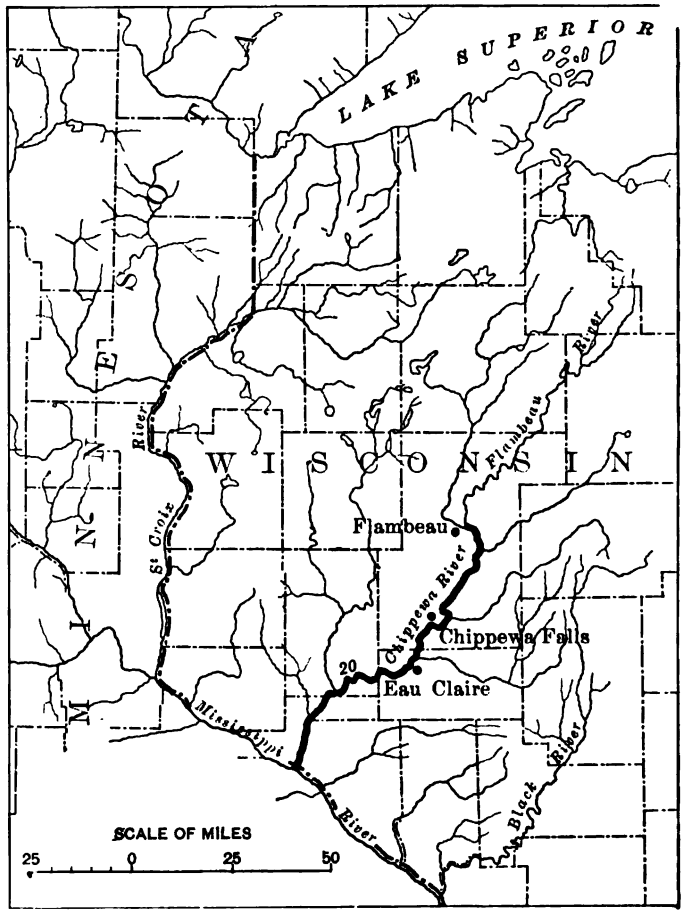

FIG. 17.—Map showing location of surveys in Wisconsin.

This level work is based on a bench mark of the Mississippi River Commission at Reeds Landing, and the distances were obtained by pacing. No plane-table survey of the river was undertaken. In this section, 64 miles in length, there is a fall of 135 feet. Eleven bench-mark tablets and 70 temporary bench marks were established, and 72 water-surface elevations were determined.

While the survey was being made the stage of the river fluctuated greatly, owing to rains and to alternate flooding and stoppage

of the stream by various lumber companies. This diversion of the water is the cause of much compiaint by the various mill owners, many of whom want a system of reservoirs constructed near the headwaters to regulate the water supply.

Owing to the slight fall, the width of the stream, and the wide bottom lands, there are no opportunities for power development upon the Chippewa above Reeds Landing until the city of Eau Claire is reached.

On Eau Claire River, a few hundred feet above its junction with the Chippewa at Eau Claire, is a 13-foot dam 300 feet long, which furnishes power for a linen mill. A few miles above the city of Eau Claire on Chippewa River the Dells Paper Company has a 20-foot dam which might be raised 3 or 4 feet by the use of flashboards. There are no power sites on Chippewa River until the city of Chippewa Falls is reached, but there are good prospects of developing power on several of the tributaries between these cities.

From Chippewa Falls to Flambeau the stadia survey of the river and adjacent banks was plotted on a scale of 1:22,500. In this distance, 43 miles, there is a total fall of 244 feet. Seven bench marks were established and 40 water-surface elevations were determined.

At Chippewa Falls a wooden 13-foot dam, owned by the Chippewa Falls Lumber and Boom Company, increases the head to 30 feet and supplies power for a large sawmill, and an electric plant which furnishes the city of Chippewa Falls with water and light. This dam could be made higher, as the local conditions are favorable, but this would interfere with a proposed plant at Paint Creek Rapids, 2½ miles upstream, to which point the water now backs up. Here there was formerly a flooding dam, but a freshet cut a channel around it to the north, and the dam has since been torn out. A 14-foot dam could be constructed at the foot of the rapids where the banks and bed of the river are sand intermingled with large bowlders. Abundant stone for construction is near at hand.

At Eagle Rapids, 4½ miles upstream, is a good site for a dam. A dam here was torn out. A 20-foot dam would back water three-fourths of a mile above the city of Chippewa, where O'Neils Creek enters from the west. One mile above O'Neils Creek is a gorge 700 feet wide. A 25-foot dam would have solid sandstone for foundation and abutments and would back water almost to the foot of Jim Falls, 5 miles above. At the small village of Jim Falls, near the site of an old flooding dam, is the best opportunity for power development on the river. This point is now under development, the company having purchased all the land needed as well as the water rights. The river flows over a series of granite ledges from 1 to 4 feet high, while the banks seem to be solid rock covered by a

few feet of sandy soil. The proposed dam will be 28 feet high and will be located at the head of the rapids. It will furnish power for a pulp mill. The dam will back water nearly to Brunne Falls, 9½ miles, and covers the Colton and Chevalley rapids. The head obtained by this dam will be 55 feet.

At Brunne Falls the best location for a dam would be at the main fall, about 650 feet above the foot of the rapids, where a 35-foot dam would back the water up to the rapids at Holcombe, 5½ miles. The river at the falls is very narrow, and at the point mentioned the banks are ledges of rock. A rocky island in the river would help in the construction a good deal.

At Holcombe the Chippewa Falls Lumber and Boom Company has an old dam with a head of about 17 feet. This is the third dam they have built there, the others having been washed out by freshets. As the lumber interests in this locality are declining, the present dam is being allowed to decay, and could be replaced with a more substantial structure for power purposes. The river here has a rock bottom and rather low, clay sides, and an 18-foot dam could be constructed on the site of the present structure, which, together with a 15-foot dam at the foot of the rapids, would not destroy any more valuable bottom lands above. This would back the water up for more than a mile above Deer Tail Creek and furnish considerable storage. From here to Flambeau, the end of the survey, there are no rapids of any consequence.

There are two railway bridges and a highway bridge across the river at Chippewa Falls and another road bridge just below Eagle Rapids. There are but few boats on the river, as during the log-driving season boats would be crushed.

The lumbering operations, which are on the decline, are controlled by the Chippewa Falls Lumber and Boom Company, with headquarters at Chippewa Falls, a thriving city of about 10,000 population, where there are a number of factories and mills. About ten miles above is the city of Chippewa, at one time the most promising town in the neighborhood, but now little more than a hamlet. At Jim Falls there is a village, but Holcombe is the only town of any importance above Chippewa Falls. Several railroad lines are being built in this section, and the agricultural and manufacturing interests are supplanting the lumber industry, while the land is generally taken up by settlers wherever the lumber has been cut, so that no second-growth timber is coming up. The whole community seems very prosperous, while numerous companies are on the point of investing capital in the manufacturing interests in the neighborhood.

The elevations of water surfaces of the river are dependent on the following table of daily gage readings by the Chippewa Falls

Lumber and Boom Company from a gage on the highway bridge at Chippewa Falls. The elevation of the zero of gage is 804.8 feet above sea level. The gage height of the highest water known had an elevation of 831.4 feet above sea level.

Gage height of Chippewa River at Chippewa Falls.

Date.	Height.		Date.	Height.	
	Ft.	*In.*		*Ft.*	*In.*
May 1	8	10	June 6	3	10
2	8	6	7	2	2
3	8	0	8	2	6
4	8	0	9	3	0
5	7	9	10	2	9
6	7	3	11	2	6
7	6	8	12	2	6
8	5	6	13	2	2
9	5	6	14	.....	
10	.....		15	1	6
11	5	6	16	1	6
12	8	9	17	1	6
13	9	6	18	1	3
14	9	6	19	0	6
15	9	1	20	2	6
16	8	1	21	.....	
17	.....		22	1	0
18	6	3	23	1	3
19	5	8	24	1	0
20	5	2	25	0	9
21	5	3	26	0	9
22	5	8	27	0	9
23	5	3	28	.....	
24	.....		29	1	6
25	5	9	30	1	10
26	6	4	July 1	3	8
27	8	8	2	4	10
28	11	0	3	5	7
29	12	5	4	9	6
30	11	8	5	10	6
31	10	3	6	10	3
June 1	8	8	7	9	0
2	7	10	8	7	9
3	6	6	9	6	9
4	5	9	10	5	1
5	4	9	11	6	0

Gage height of Chippewa River at Chippewa Falls—Continued.

Date.	Height.		Date.	Height.	
	Ft.	*In.*		*Ft.*	*In.*
July 12	6	0	Aug. 22	1	9
13	5	4	23	.....	
14	4	6	24	1	9
15	4	3	25	1	9
16	3	3	26	1	9
17	3	3	27	1	9
18	5	0	28	2	0
19	1	0	29	2	3
20	2	10	30	2	6
21	2	6	31	2	3
22	2	3	Sept. 1	2	3
23	2	3	2	2	9
24	2	3	3	2	3
25	3	0	4	2	0
26	.....		5	.....	
27	2	6	6	2	3
28	1	9	7	2	6
29	1	6	8	2	8
30	1	4	9	4	0
31	1	0	10	4	4
Aug. 1	1	3	11	5	1
2	1	6	12	7	0
3	2	0	13	7	8
4	2	9	14	9	6
5	3	6	15	12	4
6	5	3	16	13	3
7	5	3	17	12	6
8	6	9	18	11	0
9	3	6	19	9	6
10	3	10	20	8	6
11	3	8	21	7	3
12	3	0	22	6	4
13	3	3	23	5	6
14	3	2	24	4	6
15	3	6	25	3	3
16	.....		26	3	3
17	3	0	27	3	3
18	2	6	28	3	4
19	2	0	29	3	3
20	1	6	30	3	3
21	1	6	Oct. 1	3	3

Gage height of Chippewa River at Chippewa Falls—Continued.

Date.	Height.		Date.	Height.	
	Ft.	*In.*		*Ft.*	*In.*
Oct. 2	3	3	Oct. 5	7	10
3	3	6	6	8	1
4	5	9	7	8	0

The elevations in the following list are based upon a bronze tablet, marked "797 E. C," at southwest corner of the court-house at Eau Claire, Wis., the elevation of which is accepted as 797.473 feet above mean sea level. The initial point upon which these levels depend is bench mark "Bottom," of the Missouri River Commission, opposite Reeds Landing, Minnesota, the elevation of which is accepted as 672.355 feet above mean sea level. These elevations accord with the 1903 adjustment of the precise-level net.

Permanent bench marks dependent on this datum are marked with the letters " E. C." in addition to the figures of elevation.

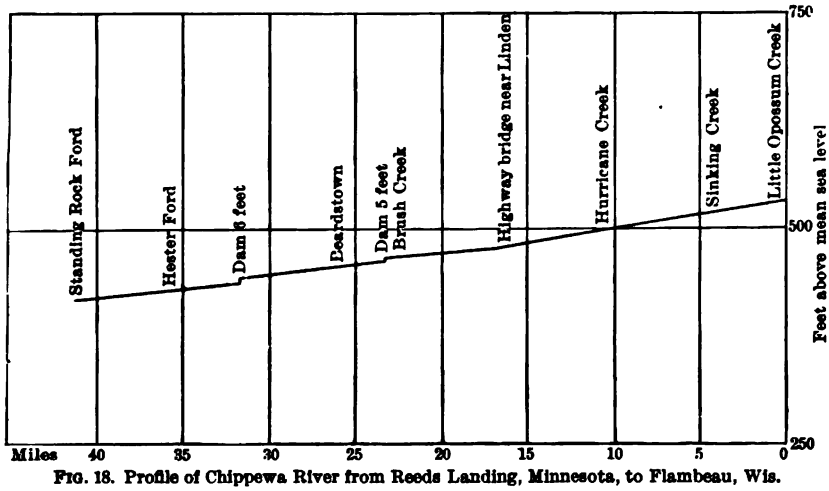

FIG. 18. Profile of Chippewa River from Reeds Landing, Minnesota, to Flambeau, Wis.

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.

Distance in miles.		Elevation in feet.
0.0	Reeds Landing, Minnesota (Miss. River Commission bench mark "Bottom"), tile and iron pipe in low flat ground, opposite, 220 meters from left bank of river, in property of Mrs. C. S. Richards, 45 meters west of Chicago, Milwaukee and St. Paul Railroad trestle to bridge, 205 meters southwest of end of trestle and small pond..	672.355

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
0.5	High water in back water of slough	672
1.4	Trevin's, at grade crossing Burlington and Chicago, Milwaukee and St. Paul railroads, top of rail	684.3
1.4	15 feet northwest of intersection of grade crossing, spike in telegraph pole	684.89
1.9	15 feet northwest of end of trestle, nail in top of fence post	680.01
2.6	Lone narrow island, lower end of, left bank of river, birch tree, nail in root of	677.46
2.6	High water	674
3.2	Private road crossing, top of rail	681.4
3.5	Government dam, 300 feet below, opposite north end of small island, left bank of river, water maple, nail on notch	680.36
3.5	High water	675
3.6	300 feet north of rapids, high water	676
3.8	Wancuda Island, 0.25 mile below north end of, left bank of river, notch cut on elm tree, nail in	681.52
4.3	North end of Government dam, 100 feet below, left channel, surface of water	677
4.5	165 feet east of river, water maple tree, notch cut in	681.13
4.5	Surface of water	678
0	Near north corner of C. W. Knight's yard, in top of limestone 8 by 10 by 26 inches, set 25 inches in ground, bronze tablet marked "682 E. C."	682.337
5.5	Opposite trestle 32 H, surface of water	680
5.8	Old Battle Slough station, in west side of switch stand, spike	685.28
6.2	Surface of water (river about 1 foot above ordinary stage)	681
6.6	Bridge No. 38 M, 50 feet south of, west side of dump, cross on stone	685.28
6.7	Bridge No. 42 M, private road crossing south of, top of rail	688.41
7.4	Bridge No. 50 M, at south end of, east side of track, nail in cross cut in cap	688.26
7.4	Surface of water	683
7.9	Private crossing, top of rail	692.1
7.9	Surface of water	685
8	Second telegraph pole north of slough, spike in	689.33
8.5	Elm tree on left bank of river, nail in notch cut in	689.36
8.5	Surface of water (1.9 feet higher than stage observed nearer mouth)	687
9	Trestle No. 60 M, top of rail	.....
9	Surface of water	688
9.6	Maxwell station, surface of water	691
9.6	Maxwell, 180 feet southwest of platform, in sandstone post 8 by 12 by 80 inches, set 27 inches in ground, bronze tablet marked "691 E. C."	691.196
10.3	Trestle No. 66 M, Little Belf Slough, surface of water	691

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
10.6	West side of railroad, near gate at private road crossing, nail in top of stump	694.91
10.6	Surface of water (is about 4 feet lower than low water)	693
11.4	South end of trestle No. 70 M, 15 feet east of railroad, cross on sandstone	701.32
11.9	Big Beef Slough, 150 feet below railroad bridge No. 74 M (is about 3 feet above low water) surface of water	695
12.3	595 feet north of bridge, on west side of track, nail in top of post	711.65
12.4	Private road crossing, top of east rail	714.61
12.8	Pawn's farm, private road crossing, top of west rail	724.3
13.4	T. 24 N., R. 13 W., just outside of Chicago, Milwaukee and St. Paul Railroad right of way, left bank of river, and 0.25 mile due west of center sec. 6, in sandstone post 12 by 6 by 30 inches, bronze tablet marked "733 E. C."	732.878
13.4	Surface of water	698
14	Round Hill, 0.25 mile below, left bank of river, black oak tree, nail in notch cut in	737.7
14	Surface of water	699
14.4	Road in front of barn	733
14.4	Surface of water	699
14.6	Round Hill, north and south road crossing on Chicago, Milwaukee and St. Paul Railroad	731.4
15.2	Road crossing on east side of railroad, spike in signboard	740.56
15.9	Private road crossing, top of rail	724.55
16.1	Durand, 100 feet north of south switch block, 12 feet east of center of track, north end of sandstone, cross	717.54
16.5	300 feet north of brewery, east and west road crossing, top of rail	720.6
16.8	Durand, road crossing north of station, top of rail	724.7
16.8	Durand County jail building, water table at southwest corner of, bronze tablet marked "724 E. C."	724.361
16.8	Upper bridge, surface of water	703
17.5	Durand, north part of, at north end of siding, 35 feet northwest of switch block, cottonwood tree, notch cut in root, nail in	727.23
	Spur line up river.	
18.2	Elm tree, left bank of river, nail in notch	707.24
18.2	Surface of water	705
18.5	Creek from east, white oak tree at, nail in notch on root	707.20
18.5	Creek, at mouth, surface of water (river is about 2 feet above low water)	706
	Main line continued.	
18.8	Northwest corner of trestle No. 96 M, nail in top of fence post	717.24
18.8	Surface of water	711
19.1	Beaver Creek, surface of water	712

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
19.1	Trestle No. 98 M, top of sandstone, at southeast end of trestle	714.55
19.7	Trestle No. 100 M, southeast corner of, spike in cap	715.60
19.7	Surface of water	713
20.4	Bear Lake, 0.75 mile north of, private road crossing, top of west rail	733.2
20.6	Private road crossing, top of east rail	735.1
21.1	Whistle post for road crossing, spike in	735.62
21.2	East and west road crossing, top of west rail	735.8
21.4	Northwest and southeast road crossing, top of west rail	737.2
22.1	Weber's house, road crossing, top of rail	745.8
22.1	Crossing post, near bottom, railroad spike	746.52
22.4	Trestle No. 106 M, section line between secs. ——— top of rail	749.64
22.8	Red Cedar, 0.33 mile south of, T. 25 N., R. 12 W., sec. 6, one-quarter corner north side of, in ground at T road east, sandstone 6 by 12 by 30 inches, bronze tablet marked "755 E. C."	755.670
23.1	Red Cedar, west part of, foundation to water tank	758.36
23.1	Red Cedar, road crossing, top of rail	758.9
23.3	Surface of water	721
23.9	Private road crossing, top of rail	735.2
24	Private road crossing, spike in base of first telegraph pole north of	731.37
24.2	Red Cedar Junction, at switch block, top of east rail	729.3
24.4	Red Cedar Junction, surface of water at bridge	721
24.6	Trestle No. 108 M, at southwest corner, nail in top of fence post	730.45
24.6	Surface of water	722
25.7	Tyrone (abandoned station), 750 feet south of, spike in telegraph pole	727.97
25.7	Surface of water	724
25.8	Tyrone, at road crossing, top of rail	732
26.4	Private road crossing, top of rail	731.2
26.7	Trestle No. 116, fence post at southwest corner of, nail in top of	732.96
26.7	Surface of water	724
26.9	Private road crossing, top of west rail	733.24
27.1	Railroad spike in crossing post	731.5
27.4	Road crossing (second one north of public crossing), top of rail	732.9
27.9	Trestle No. 118 M, at southeast corner of, in top of fence post	733.04
27.9	Surface of water	728
28.8	Meridian, T. 26 N., R. 12 W., sec. 14, north part of, at southeast corner of Iver Brock's residence, in stone foundation, bronze tablet marked "740 E. C."	739.923
28.8	Road crossing, top of rail	739.2
29.4	Private road crossing, top of rail	739.8
29.6	Trestle No. 124 M, at east end of, nail in top of fence post	738.46

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
29.6	Surface of water	733
29.7	North and south road crossing, top of rail	739.6
30.1	North and south road crossing, cross on stone	740.30
30.1	Road crossing, top of north rail	741.7
31	Road crossing, spike in telegraph pole	745.02
31	Wagon bridge, surface of water	739
32.2	South side of railroad, 60 feet west of large spring, cross cut in sandstone	751.82
32.2	Surface of water	741
33	Spike in base of telegraph pole	747.85
33.7	Opposite small island, on highest point of large sandstone bowlder, cross cut	753.19
33.7	Surface of water	743
34.1	On bank of river at right of way fence, sandstone bowlder, cross cut in top of	754.70
34.5	Rock Creek, surface of water	744
34.7	Private road crossing, top of rail	752.9
34.9	Trestle No. 144, at northwest corner of, nail in cross cut in cap	751.22
35.8	Caryville, T. 26 N., R. 11 W., sec. 11, east part of, at northwest corner of post-office, Strand's general store, in stone foundation, bronze tablet marked "760 E. C."	760.144
35.9	Road crossing, top of rail	757.7
	[Line continued along highway.]	
36.3	Wagon bridge over West Creek, in top of pile at east approach, nail	753.98
36.3	Surface of water	746
37	East of small island, water maple 40 feet east of river, on left bank, nail in root of	749.63
37	Surface of water	747
38.3	Powell Lake and Chippewa River roads, 75 feet east of junction, small double elm tree, nail in root of	756.15
39.1	Surface of water	752
39.5	Surface of water	752
40.7	On left bank of river, at east end of long log boom, nail in maple stump	763.11
40.7	Surface of water	755
41.3	Coolies Lake, near outlet, B. A. Churchville residence, at southwest corner of, in foundation, bronze tablet marked "779 E. C."	779.356
41.4	Surface of water	758
42.4	Porterville, 0.75 mile south of, wagon road culvert, nail in top of pile	763.92
42.4	Surface of water	761
43	Old Porter mills, nail in root of large water maple	764.84
43.3	T roads	767

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
43.3	Creek, mouth of, surface of water	764
43.8	On river bank, 30 feet west of road, nail in top of stump	767.85
44.1	Surface of water	764
44.8	Charles Bannon's residence, 120 feet southeast of, at gate, nail in white oak stump	771.08
44.9	Lower Creek, road crossing on Chicago, Milwaukee and St. Paul Railroad, top of rail	773.4
44.9	Surface of water (higher than has been for 2 years)	768
45.5	Shawtown, 1 mile south of, T. 27 N., R. 10 W., sec. 36, northeast corner of, in stone foundation at northwest corner of Henry Trimble's residence, bronze tablet marked "781 E. C."	780.84
45.5	High water, in 1884	777
45.8	Road crossing	776.5
45.8	Surface of water	769
46.5	Shawtown, 200 feet south of railroad bridge, spike in base of telegraph pole	783.98
46.5	Under bridge, surface of water	769
46.6	Menomonie street crossing, top of rail	777.6
47.6	Eau Claire, crossing of Niagara and Seventh street	781.2
48.1	East entrance to high school, first window to right, in sill, cut in center	797.93
48.3	Eau Claire, at southwest corner of court-house, bronze tablet marked "797 E. C."	797.473
48.4	Crossing of Grand and Oxford avenue, top of rail	791
48.7	200 feet south of railroad bridge, spike in base of crossing post	787.33
48.8	Center of railroad bridge over river	788.3
48.8	Eau Claire River, mouth of, surface of water under bridge (June 2)	770
	[Spur line, June 9, up Eau Claire River from junction. Stage of water 6.5 lower.]	
.1	Junction of Chippewa and Eau Claire rivers, June 9, foot of first dam at mouth of, on Eau Claire river	763.5
.1	Head of same dam	774
.75	Foot of second dam	774
.75	Head of second dam	786.8
	[Main line continued June 2. River is 6.5 feet higher than a week later.]	
49	Eau Claire court-house, 0.7 mile north of, at Chicago, Milwaukee and St. Paul Railroad station, top of rail	786.05
49.1	Forrest street crossing of spur to paper mill, top of rail	778.6
49.4	Elm street crossing, top of rail	780.3
49.4	The Dallas Paper Mill Company dam, foot of, surface of water	772
49.4	The Dallas Paper Mill Company dam, head of, surface of water	793
49.8	Chicago and Northwestern Railroad bridge over river, south corner of east pier, cross cut on	804.36

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
50.6	Chicago and Northwestern, at mile post St. Paul 87, top of rail	843.1
50.7	Duluth Branch, at overhead road crossing, top of rail	851.8
50.8	Duluth branch, Chicago and Northwestern Railroad, on east side of railroad, opposite yard-limit post, spike in base of telegraph pole	858.56
51	Road crossing, top of rail	871.3
51.4	Mile post 1, top of east rail	882.8
51.6	Power house at crossing of Chicago, Milwaukee and St. Paul and Chicago and Northwestern railroads, 1,100 feet south of, spike in telegraph pole	882.09
51.9	Grade crossing, top of rail	881.2
52	Chicago, Milwaukee and St. Paul and Chicago and Northwestern railroads, grade crossing, top of rail	880.2
52.6	Road crossing, top of west rail	843.5
52.6	20 feet west of north cattle guard to road crossing, in base of fence corner post, spike	840.09
53.2	Road crossing, top of rail	813.8
53.3	Second pole west of road crossing, spike in	807.97
53.5	Dalles Mill station, road crossing, top of west rail	804.2
54.4	Road crossing on line between Eau Claire and Chippewa counties	813
54.4	County line crossing, in north cattle guard, nail in top of fence post	815.18
54.8	East and west road crossing, top of east rail	821.1
54.8	Surface of water	793
56.1	La Fayette, road crossing at old site of, top of west rail	817.4
56.1	Surface of water	794
56.1	La Fayette, second telegraph pole above road crossing at old site of, spike in	818.75
57.3	North and south private road crossing, spike in black oak tree	815.96
.0	Surface of water	794
57.4	Road crossing east and west	821.9
58.3	Badger Mills, road crossing just below north switch block	817
58.3	Halle Lake, Badger Mills, surface of water	815
58.4	Badger Mills, just south of waiting shed, spike in crossing post	818.19
58.4	Badger Mills, opposite waiting shed, top of east rail	820.2
58.76	Badger Mills, summer hotel, in ground in lawn of, 50 feet due west of front window, sandstone post 10 by 8 by 30 inches, bronze tablet marked "827 E. C."	827.716
59.4	150 feet west of P. C. mark, 150 feet south of gate, spike in base of telegraph pole	831.45
59.4	Surface of water	797.3
60.5	Surface of water	801
60.6	Trestle No. 216, in sleeper at west end of, painted cross on bolt	833.51
61.1	Gravel Island, crossing post just below, spike in base of	855.19
61.1	Gravel Island, slough, mouth of, surface of water	803

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
62.1	Surface of water	805
62.2	Spike in base of crossing post	840.31
62.2	Road crossing, top of rail	842.4
62.8	Central Junction, Chicago, Milwaukee and St. Paul Railroad and Wisconsin Central Railroad, switch block at	832.4
62.9	East side of railroad, spike in base of telegraph pole	832.9
62.9	Road crossing, top of rail	833.9
63	Center of Chicago, Milwaukee and St. Paul Railroad bridge, top of rail	834.03
63	Surface of water under bridge	805
63.3	Junction of Chicago, Milwaukee and St. Paul Railroad and Wisconsin Central Railroad (main line), top of rail	840.3
63.8	Chippewa Falls, 20 feet south of water tank, spike in base of telegraph pole	830.63
63.9	Chippewa Falls, Taylor street crossing, top of rail	833.7
63.9	Chippewa Falls, under bridge, foot of dam, surface of water	807
64.31	Chippewa Falls, northeast corner of city building containing fire department and city jail, in foundation, bronze tablet marked "840 E. C."	840.468
64.4	Chippewa Falls, above dam, surface of water	840
	[Flying levels by F. T. Fitch, field assistant, Chippewa Falls, up Chippewa River to Flambeau.]	
.0	Highest water mark on record, recorded by Chippewa Falls Lumber and Boom Company, Sept. 10, 1884	832
.0	Second highest water mark of Chippewa River, recorded Dec. 3, 1896	831
.0	Lowest water mark of Chippewa River, reading taken at Chippewa Falls	804
.0	Highway bridge at falls, surface of water	806
.0	Chippewa Falls, surface of water	826
.0	Crest of dam of Chippewa Falls Lumber Company, surface of water	839
3.7	Paint Creek Rapids, foot of, north bank of river, 50 feet from water, top of bowlder, chiseled square	844.54
5.5	Yellow River, mouth of, surface of water	852
8	Eagle Rapids, foot of, surface of water	854
9.2	Eagle Rapids, head of, surface of water	867
10.7	Surface of water	871
13	Foot of rapids, surface of water	881
15.7	Jim Falls, east side of river at edge of water, nearly opposite Pitch Hotel, at foot of rapids, in granite ledge, chiseled square	902
15.7	Surface of water	901
16.6	Head of rapids, surface of water	936
17.9	Coltons Rapids, foot of, surface of water	942.2
19.2	Coltons Rapids, head of, surface of water	945

Elevations on Chippewa River, from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
19.2	Chas. Richards, near house occupied by, 150 feet south of road intersection, at edge of water, rock, chiseled square	947.40
20.2	Shaw Creek, 400 feet above mouth of, surface of water	.....
22.9	Bob Creek, mouth of, surface of water	954
25.7	Chevalley Rapids, foot of, surface of water	961
26.9	Above rapids, surface of water	966
26.9	Brunne Falls, at boat landing, west bank of river, below main falls and just above Chevalley Rapids, 125 feet south of old house, 50 feet from water, bowlder 2 feet square, chiseled square	984.19
27	Brunne Rapids, foot of, surface of water	967
28	Brunne Rapids, head of, surface of water	993
29.5	Fisher River, mouth of, surface of water	995
32.7	Holcombe, foot of rapids, surface of water	1,004
33.2	Holcombe, foot of dam, surface of water	1,020
33.2	Above dam, surface of water	1,036
33.2	South entrance to bridge over flooding dam, 500 feet west of, south side of highway, 50 feet south of river, on bowlder in fence, chiseled square	1,046.55
39.7	Deer Tail Creek, mouth of, surface of water	1,036
43.3	Flambeau, post-office, at intersection of Flambeau and Chippewa rivers, on point of land, nail in root of tree	1,055.09
43.3	Junction of rivers, surface of water	1,050

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Author.

Hall, W. Carvel.

. . . River surveys and profiles made during 1903, arranged by W. Carvel Hall and John C. Hoyt. Washington, Gov't print. off., 1905.

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U. S. Dept. of the Interior.

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Water-Supply and Irrigation Paper No. 116 Series { J, Water Storage, 11
M, General Hydrographic Investigations, 14

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

WATER PROBLEMS

OF

SANTA BARBARA, CALIFORNIA

BY

J. B. LIPPINCOTT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., May 12, 1904.

SIR: I have the honor to submit herewith, for publication as a water-supply and irrigation paper, a report on the water problems of Santa Barbara, Cal., transmitted by Mr. J. B. Lippincott.

As the city and suburbs of Santa Barbara form one of the most attractive and productive districts in southern California, a thorough knowledge of the water supply of the region is of the utmost importance. It is thought that the facts brought out in the report will be of much interest.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

GIBRALTAR RES.
MONO RES.
2000
34°
30'
MAIN RIVER RES.
Blue Canyon
SANTA YNEZ MOUNTAINS
Mission Canyon
Cold Spring Canyon
Juncal Canyon
JUNCAL RES.
T.S.N.
34°
30'
4000
SANTA BARBARA
Montecito
Summerland

WATER PROBLEMS OF SANTA BARBARA, CAL.

By J. B. Lippincott.

INTRODUCTION.

The Santa Barbara coast extending from Goleta to Carpinteria, including the city and suburbs of Santa Barbara, is naturally one of the most attractive and productive districts of southern California. It is, however, deficient in water supply.

Desiring a broad and comprehensive study made of this locality, with a view to a solution of the problems involved, the city and county of Santa Barbara have requested (1) that the topographic work of the Geological Survey be extended so as to cover this district, and (2) that the hydrographic branch of the Survey make an investigation of the water problems involved. These topographic surveys have now been made, and the maps of the Goleta, Santa Barbara, Santa Ynez, and Mount Pinos quadrangles have been published. The Santa Maria quadrangle has been surveyed and the map is now being engraved. This will complete the mapping of the county. These topographic maps are of the very greatest assistance and importance in determining relative elevations, areas and elevations of drainage basins, and possible tunnel locations through the Santa Ynez Range.

In the hydrographic investigations the city of Santa Barbara has cooperated, paying one-half of the expense connected with the maintenance of a gaging station on Santa Ynez River and Mono Creek, on which streams daily observations have been made for silt, volume of flow, and mineral impurities of the water, and also approximately 25 per cent of the expense connected with the preparation of this report. This portion of the work, therefore, is in the nature of a joint investigation by the city of Santa Barbara and the Geological Survey, all of the field work and investigation being done by the Survey and a portion of the expense being paid by the city of Santa Barbara.

LOCATION AND DRAINAGE OF THE DISTRICT.

The district under investigation extends from Ventura River in Ventura County along the coast as far as Goleta in Santa Barbara County, and more particularly into the high mountainous districts of Ventura and Santa Barbara counties lying on the north side of the Santa Ynez Range and including the drainage basin of Santa Ynez River and its tributaries.

The coastal plain fronting the ocean consists of a series of old marine beaches and undulating foothills facing Santa Barbara Channel. Views of this coastal plain are shown in Pl. II. This district is of great natural beauty, and has become the home not only of agriculturists and horticulturists, but also of many eastern people who have sought it for recreation and health. It is one of the most attractive regions in California. The winds are mild, those from the south being tempered by the Pacific Ocean, and those from the north being barred out by the Santa Ynez Range, which parallels the coast, rising to elevations of from 3,000 to 4,000 feet and presenting a bold and attractive background to the undulating foothill districts. (See Pl. I.)

The streams flowing from the southern slope of this range are precipitous and have short drainage basins of small area. This topography produces a torrential stream condition after rains, followed by a period of extreme low water in time of drought. The range is formed chiefly of shale and sandstone, the strike being parallel to the coast and the dip nearly vertical, inclining somewhat to the south. This geologic formation admits of a number of small but permanent springs in the canyons eroded by the streams, and is also favorable to the development of water by tunnels run at right angles to the line of strike. Beyond the crests of the Santa Ynez Range is the drainage basin of Santa Ynez River. A second range of mountains, consisting of the crest of the Coast Range and culminating in Mount Pinos, the elevation of which is 8,826 feet, rises to the north and trends parallel to the Santa Ynez Mountains. These higher mountains are drained by streams running in a southerly direction and uniting with Santa Ynez River proper, which runs close to the northerly base of the Santa Ynez Mountains, flowing westerly and paralleling the Coast Range. It has a total length of about 70 miles, with flat grades, and offers frequent opportunities for impounding water in storage reservoirs.

The results of the investigations indicate that a solution of the water problem for the coast district lies in impounding the flood waters in the drainage basin of Santa Ynez River and conveying them to Santa Barbara through a long tunnel beneath the Santa Ynez Range.

A

B

VIEWS OF SANTA BARBARA AND VICINITY.

REVIEW OF EARLIER WORK BY OTHERS.

It is here deemed proper to review the work which has been done along this line in the past by other engineers, both for the city of Santa Barbara and for the Santa Barbara Water Company. The first report was made for the city of Santa Barbara on October 19, 1889, by George F. Wright, member American Society of Civil Engineers, and at the time city engineer of Santa Barbara. The second report was presented on July 2, 1896, by Ernest J. S. Purslow, civil engineer for the Santa Barbara Water Company. Both of these gentlemen, who are now deceased, were residents of Santa Barbara, engineers of distinction, men of good standing in the community, and thoroughly acquainted with local conditions. In general their judgment respecting the subject here under consideration is approved by the present writer, both from personal knowledge of the locality and from observations elsewhere. Their opinions particularly with reference to local water supplies on the south side of the range are worthy of acceptance, and it was not deemed necessary or advisable to make further field examinations over this ground which they had previously covered in detail. Because these reports were made a long time ago and are now unfamiliar to many new residents, and are out of print, it is considered advisable to briefly review them.

REPORT OF GEORGE F. WRIGHT, 1889.

NEEDS OF DISTRICT.

Mr. Wright states: "I have endeavored to cover the whole field in my report, trusting in many cases to previous examinations and surveys made by myself, aided by the available maps of that portion of the territory lying south of the summit of the Coast or Santa Ynez Range of mountains." He calls attention to the fact that even at that time the city had never had an ample water supply to meet its demands, a condition which, as all the residents of the district are well aware, has never been materially changed. He states further: "The immediate necessity demands a supply of 2 million gallons per day (equivalent to 200 gallons per capita for 10,000 persons), which will certainly be increased to 3 million gallons; and probably 4 million gallons, per day before many years." This statement was made on the assumption that the city, with an ample water supply, would have a vigorous growth, and a development proportional to that of other towns of southern California as suitably located and having adequate supplies. In marked contrast with this demand, he states that the low-water flow of Mission Creek (a present source of supply) is reported to fall as low as 300,000 gallons daily in midsummer, and that a trial test of the De la Guerra wells showed an average daily output of 600,000 gallons at that time.

STREAMS SOUTH OF COAST RANGE.

A complete investigation was made by Wright of all the adjoining drainage basins, extending from Rincon Canyon on the east to Cañada Refugio on the west, during the summer of 1889. The rainfall at Santa Barbara had been 21.44 inches during the preceding winter, and 21.71 inches the winter before that—unusually good records, as the Santa Barbara mean is only 16.78 inches. Consequently Mr. Wright's figures on stream flow are above what should be accepted as an average condition. His table descriptive of the streams is given below.[a]

TABLE 1.—*Streams east of Santa Barbara and south of Coast Range.*

Name of stream.	Catchment area in square miles.	Distance from city in miles.	Daily flow in miner's inches (1889).[b]	Remarks: Flow in miner's inches.
Rincon, proper	8.8	17	5.8	June 16, 1900: 1.5.
Gobernador	7.8	16	29.0	
Carpinteria, including Sutton	5.3	15	3.9	June 16, 1900: 0.1.
Santa Monica	3.6	11	11.6	
Parida, including Oil	3.3	10	15.5	
Ficay	1.4	8	15.5	
Dinsmore	3.0	6	11.6	July 18, 1902: 3.0.
Cold Spring	3.8	4	11.6	
Mission, including Rattlesnake	5.7	1	23.2	June 14, 1900: 1.0. June 17, 1900: 2.5.
Total daily summer flow			127.7	

[a] During the last year the United States Geological Survey has made a detailed topographic field survey of the mountainous district in the vicinity of Santa Barbara, indicating in contours the area of drainage basins, together with their altitude. These maps are more accurate than any previous ones, and have been used in determining the drainage areas of all the streams described by Wright that could be recognized from his names. In each case the area has been determined above the point where the stream issues from the foothills or mountains. In the case of a few of these streams other measurements are available for later years. These are included and show, particularly for the year 1900, a marked decrease in volume over that measured by Wright. The rainfall in the year 1899–1900 at Santa Barbara was 12.68 inches.

[b] A miner's inch is taken as equal to one-fiftieth of a cubic foot per second, or a flow of 12,925 gallons per day.

TABLE 2.—*Streams west of Santa Barbara and south of Coast Range.*

Stream.	Catchment in square miles.	Length in catchment.	Distance from city in miles.	Daily flow in miner's inches.	Remarks: Flow in miner's inches.
Arroyo Burro	.....	2.5	2.5	11.6	June 17, 1900: 1.5.
Maria Ygnacia	5.7	2.0	6.0	[a] 11.6	
San Jose	6.0	2.5	7.0	13.6	July 30, 1900: 38.1.
San Pedro	2.7	2.0	9.5	3.9	
Arroyo Carnero	3.3	2.0	10.0	3.9	
Annes	4.0	1.0	12.0	3.9	
Annito		1.5	13.0	1.9	
Tecolote	5.2	2.5	14.0	13.6	
Aguila	4.5	2.0	15.0	5.8	
Dos Pueblos	6.7	2.0	17.0	27.2	
Cañada Verde (Las Varas)	2.5	2.0	18.0	3.9	
Cañada Llaces	1.5	2.0	20.0	3.9	
El Capitan	1.5	1.0	22.0	11.6	
Cañada del Corral	1.0	1.0	23.0	7.7	
Cañada Refugio	2.0	2.0	25.0	15.4	
Total	.....	.....	.....	139.5	

[a] Laguna Blanca Water Company.

Wright correctly states that the grades of these local streams on the south side of the mountains are very steep, affording no opportunities for the construction of storage reservoirs. He also states that while it might be possible to divert some of these storm waters by means of large canals into basins in the flat lands to the side, the work would be exceedingly expensive and impracticable.

The conclusion that he reaches with reference to the streams on the south side of the Coast Range is as follows:

I do not deem it practicable to secure an ample supply of water for Santa Barbara south of the Santa Ynez Range of mountains, for the following reasons:

1. The aggregate daily summer flow of the entire watershed from Rincon Creek to and including Refugio Creek is less than 4 million gallons per day.

2. This flow is all claimed by riparian owners, water companies, and individual water claims.

3. Storage-reservoir sites of sufficient capacity and elevation do not exist along the streams, if at all. The construction of numerous small reservoirs would increase the operating expenses and also the first cost of construction.

4. Diverting dams in the streams would be necessary to turn the winter flow, and the conduits leading to the storage reservoirs would necessarily be large and expensive.

5. It is very doubtful if the city of Santa Barbara could establish a claim on the waters of these streams which would enable her to obtain them through legal process. Where it is possible to do so, however, the city can not afford to appropriate water which, if not now needed, soon will be, for the supply of the rapidly increasing population of the Carpinteria and Montecito valleys on the east and the Goleta and Dos Pueblos on the west.

UPPER DRAINAGE BASIN OF SANTA YNEZ RIVER, ALSO SANTA BARBARA AND VICINITY.

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STREAMS NORTH OF COAST RANGE.

Having failed to find an adequate supply of water on the south side of the range, the investigations of Wright were extended to the north side of the range, into the basin of Santa Ynez River. Surveys to determine relative elevations were made, and detailed reports on two reservoir sites, one known as the Juncal, near the head of the Santa Ynez, and the other as the Main River reservoir site, below the mouth of Blue Canyon. A general view of the basin of Santa Ynez River is shown in Pl. III, *B*.

From a study of the rainfall data available at the time of his report Wright concludes that it will be necessary to have a storage reservoir capable of holding water from years of average or excessive rainfall for years of deficient rainfall. He believes that in some winters there will be little, if any, storm water in these streams. From April, 1876, to October, 1877, inclusive, there was a period of drought of nineteen months in which the rainfall was insufficient to much more than supply evaporation. On his basis of 200 gallons per day per capita, for a population of 20,000, requiring 4 million gallons per day, this would call for a storage of 2,280 million gallons, which is equal to 7,000 acre-feet of water, an acre-foot being the volume of water sufficient to cover 1 acre 1 foot deep, or 43,560 cubic feet.

JUNCAL RESERVOIR SITE.

The Juncal reservoir site was determined to have the following capacities with the heights of dam stated:

TABLE 3.—*Capacities of Juncal reservoir with various heights of dam.*

Height of dam in feet.	Capacity in gallons.	Capacity in acre-feet.
200	4,000,000,000	12,276
175	2,352,000,000	7,218
150	1,877,000,000	5,760
125	1,437,000,000	4,410
100	1,050,000,000	3,222
75	705,000,000	2,164
50	350,000,000	1,074

A dam 200 feet high would be 550 feet long on top, and one 100 feet high would be 272 feet long on top. Purslow in his report estimates that a dam at the Juncal 100 feet high, with a diversion conduit to Santa Barbara, would cost $300,000. The area of the drainage basin is given as 23.5 square miles by both Wright and Purslow. From the topographic surveys of the United States

A. MONO CREEK DAM SITE AND GAGING STATION.

B. SANTA YNEZ BASIN ON PROJECTED LOCATION OF OLD CITY TUNNEL.

Geological Survey it is found that they were seriously in error, and that there is but 13.4 square miles of area naturally tributary to this reservoir site. This directly affects the value of the Juncal as a storage reservoir. Wright gives certain figures showing that, in his judgment, the water supply would be always sufficient to meet the demands upon this reservoir. At the time the reports of both Wright and Purslow were written little available data existed indicating the flow that might be expected from drainage basins on the Pacific coast, particularly in southern California. Estimates were therefore based upon observations on eastern streams. Since that

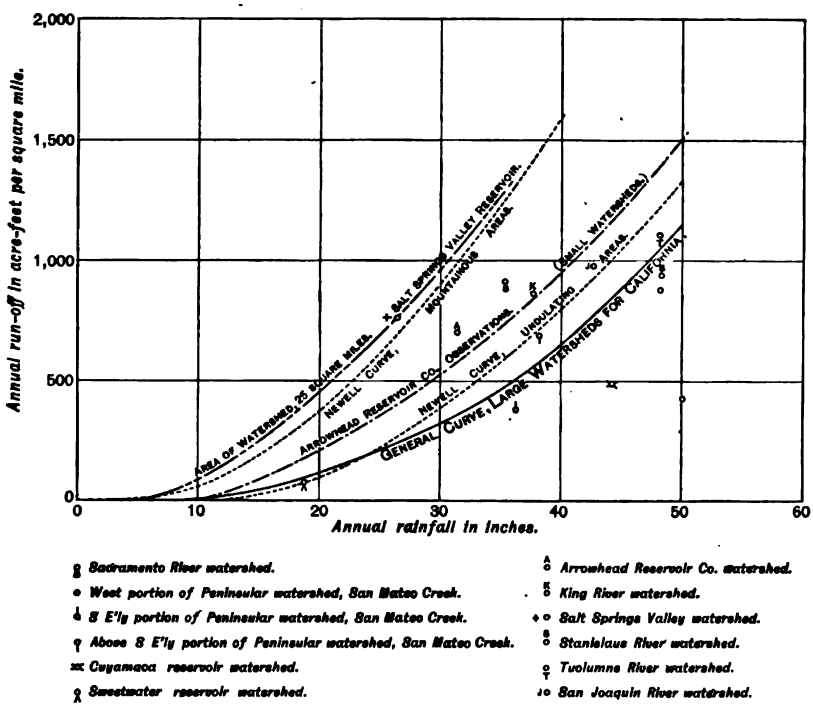

FIG. 1.—Diagram showing relation of rainfall to run-off for California streams. (For description see page 50.)

time, however, the United States Geological Survey has been measuring California streams and determining drainage areas and their rainfall, and there is now better information available on this subject. The whole trend of these late stream measurements has been to show that estimates of run-off for southern California, particularly those based on observations on eastern rivers which were previously considered as comparable, give excessive and unreliable results. While it is impossible to predict accurately what the discharge from any given drainage basin will be, nevertheless, from examinations made of the basin of the Santa Ynez and the application of average conditions observed in localities somewhat

similar and of a mountainous character, it is possible to form an approximately correct idea of the true results. Table 12 shows the estimated run-off from the drainage basin of the Juncal and neighboring streams in detail. From an extended comparison of rainfall data it is believed by the writer that the precipitation on average years in the basin of the Santa Ynez may possibly reach 22 inches. But since late records indicate less rainfall, the Santa Barbara mean of 16.78 is used by the author as the basis of his estimates in table 12 (p. 53). Wright considers that it will be over 20 inches throughout the drainage basin, and Purslow that it will be 27 inches. The rainfall in the mountains varies in the same ratio for wet and dry years as the rainfall at Santa Barbara city. The first rains are absorbed by the ground and retained in the soil until evaporated either from the surface or by the growing plants. It takes about 9 inches of rain to meet these demands, and, generally speaking, no material stream flow will result from a winter's rain unless it exceeds this amount, provided all of this precipitation does not occur in hard successive storms, in which event there would be run-off; usually, however, there will be no stream flow unless the winter rain exceeds 9 inches. When these demands of evaporation are met, the succeeding storms furnish more and more of a water supply for the streams, and the per cent of rain so discharged increases in a growing ratio.

From the studies above referred to, assuming a rainfall of 25 inches in this basin, it is concluded that during the year 1897–98, when the rainfall at Santa Barbara amounted to 4.99 inches, there would have been no high-water stream flow in the mountains. In 1898–99 there would have been available at the Juncal reservoir 1,114 acre-feet; in 1899–1900, 1,367 acre-feet. This is a three-year mean of 827 acre-feet, which would yield a supply of but 730,000 gallons per day, evaporation not being deducted. These figures, compared with Wright's estimated necessary supply of 4,422 acre-feet annually to meet future conditions reasonably within sight (20,000 people), show that the Juncal reservoir site and drainage basin would be inadequate to meet the demands of the city of Santa Barbara. The conclusion of Wright or of Purslow that the Juncal alone is a suitable source for a water supply for the city can not be accepted, although it may be used properly as a supplemental reservoir for hold-over purposes, its waters being liberated at such periods as may be necessary to make up for deficiencies in reservoir sites lower on the stream. In conclusion Mr. Wright makes the following statement:

I consider the Santa Ynez River above the mouth of Blue Canyon to be not only an available source of supply, but the only source possible for the future supply of Santa Barbara with an abundance of good potable water, for the following reasons:

1. Not only the sources of the streams but the entire river are uncontaminated by any of the organic wastes pertaining to civilization, and from the rugged nature of the country are likely to remain so. The sandstone gathering-grounds are of the best class for delivering water free from mineral impurities.

2. The elevation and capacity of the storage sites and the extent of the catchment insure an ample supply of water in all seasons.

3. The riparian rights in that portion of the stream sought to be appropriated are merely nominal, as none of the summer flow above Blue Canyon ever appears on the surface as far down as the San Marcos rancho. The only riparian owner is therefore the owner of the Los Prietos y Najalayegua rancho.[a] This right can probably be purchased, or if not, can be condemned by legal process.

4. The expansive capacity of the district for increasing the supply to meet all possible demands is ample and in excess. This feature alone, other things being equal, should decide in favor of this source of supply.

5. Storage reservoir sites are numerous and ample. The fall of the stream being comparatively light, renders it practicable to arrest the entire flow to the extent required by the demand.

6. The expense of constructing a thoroughly efficient and permanent system of works is no greater than would be the cost of works of equal capacity on the coast side, and maintenance will be much less.

I also recommend the construction of the works as a whole. Omitting the storage reservoir is simply gambling on our good luck, viz, that we will not have a dry season this year or next, and so on until we do get a dry year, when it will be too late to save ourselves from great discomfort and possible pecuniary loss.

REPORT OF E. J. S. PURSLOW, 1896.

Mr. Ernest J. S. Purslow, deceased, a civil engineer, living in Santa Barbara at the time and employed by the Santa Barbara Water Company, investigated in 1896 the same questions covered by Wright's report of 1889. As engineer for the water company, he would naturally have a point of view somewhat different from that of the representative of the city.

Purslow states that the present Santa Barbara Water Company, which consolidated the water rights on Mission Canyon and the De la Guerra wells, was incorporated in January, 1889. This was done in order to increase the available water supply then obtained from Mission Creek by a gravity system of diversion, and from the De la Guerra wells, located in the city limits, by a pumping system.

NEEDS OF DISTRICT.

Purslow says:

The present water supply is so inadequate and incomplete that it is a physical impossibility for the city to increase in size or population, or for the surrounding country to advance in development, until water is procured from a source other than those in the immediate vicinity, which are now all used to their fullest capacity. The scarcity of water is the first impression that visitors receive, and many who have desired to make this their home have abandoned the idea owing to the gravity of this drawback.

[a] On December 22, 1903, this ranch was included in the Santa Barbara Forest Reserve, lien scrip having been issued to the owners for it.

By the general introduction of meters and the most economical type of service taps the supply of 130 gallons should be ample for all purposes; at which rate the immediate demand of the present population would be about 1 million gallons per diem. The total supply at present, during the dry months of a year with average rainfall, is about 600,000 gallons per diem, about half from the Mission streams and half from the De la Guerra wells.

Nothing has retarded the advance of the city so much as the condition of the water supply, and nothing will promote its future prosperity and growth as much as a remedy for this condition. The present demands of the city being upwards of 1 million gallons per diem, a system could not be considered adequate which will not have a capacity to supply at least 1,500,000 gallons per diem as soon as work can be constructed, with means for subsequently increasing the supply with the growth of the city.

The suburbs of Santa Barbara, and the land extending easterly and westerly from the city, are improved only to the extent to which the waters of the small mountain streams have been made available, principally at points adjacent to and riparian on these streams. West of the city, where small quantities of water are obtained, the land is devoted principally to horticulture, and where water is not obtainable it is used as grazing and farming land. East of the city lies the famed district of El Montecito, which is inhabited, to the extent to which the small streams can supply water, by a class of people who for the most part have independent means, many of whom have built substantial and handsome houses and beautified their grounds, and among whom there are enough people of intellectual pursuits and tastes to form a nucleus which makes it especially attractive for that class of people. It is primarily and distinctively a residence district. Consisting of a gentle slope from the foothills toward the channel, broken and diversified by the natural watercourses, which, though bereft of water during the summer months, are lined with natural timber growth, backed and protected on the north by the Santa Ynez Mountains, nearly every spot commanding a comprehensive and magnificent view of the channel and coast line and the distant islands, possessing the most equable climate in the world and everything else which Almighty God could give except plenty of water, it is destined to become one of the garden spots of the world.

Land which has water is sold at from $500 to $1,000 an acre, and although land has very little productive value without water, such dry land is held and readily sold in El Montecito district at from $250 to $500 an acre. In spite of the unprecedented business depression of the past two years, sales of this land have been made during this period of some 40 tracts scattered through this district, aggregating some 670 acres, at an average price of about $330 an acre. There is no other residence district in California where prices for bare, dry, suburban or agricultural land have been so maintained and sales so extensively made during the past two years. El Montecito comprises about 4,500 acres of land susceptible of irrigation, only a small fraction of which is supplied with water for more than domestic purposes. The duty of water here for full-bearing lemon orchards has been found to be one miner's inch to 10 acres of land with the average soil, a miner's inch being equivalent to a continuous flow of 12,960 gallons per diem. Many lemon orchards have been planted during the past two years on tracts of land which have appurtenant to them such small allowances of water that it is feared that the trees will die before reaching full maturity. When orchard trees are young and small a very small quantity of water suffices to moisten the soil immediately surrounding them; but, as they increase in size and their roots extend, it is necessary to use water enough to irrigate the whole orchard surface. The owners of such orchards will be compelled to purchase more water or see their years of labor end in failure. Ornamental grounds, vegetables, oranges, and other fruits require about the same quantity of water as lemons.[a]

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[a] The tunnel line from the lower reservoir sites on the Santa Ynez (see p. 41) will command all the lands of El Montecito as well as of the city of Santa Barbara. The elevation of the south portal of the present city tunnel is 1,393 feet above sea level. The new tunnel line proposed through Mission Canyon will be at an elevation of 1,186.46 feet (Geological Survey datum).

POSSIBLE SUPPLY.

Purslow then proceeds to show that the proper and adequate solution of the water problem for Santa Barbara and vicinity consists of the storage of the storm waters of Santa Ynez River and their diversion by means of tunnel lines to the south side of the range. He states that there are three available sites for storage reservoirs on lands owned by the water company on the Santa Ynez—one in Blue Canyon, which he afterwards condemns as an impracticable proposition because of its expense and small drainage area; one on the main river near the confluence of the Blue Canyon with the Santa Ynez, which he names the Main River reservoir site, and which has a large storage capacity; and a third, the Juncal reservoir site, near the headwaters of the stream.

BLUE CANYON SITE.

He states that the Blue Canyon site is located at an elevation of 1,500 feet above sea level, with a drainage area of only about 8 square miles. A contour survey which he made showed that a dam 100 feet high above the bed of the gorge would impound 1,500 million gallons, equivalent to 4,600 acre-feet. He admits that the local drainage naturally tributary is totally inadequate to fill this reservoir. It would require a tunnel 10,550 feet long to connect this reservoir with the south side of the mountains.

MAIN RIVER SITE.

In describing the Main River reservoir site he said: "This is one of the best in California"; certainly a very singular statement for an engineer to make, in view of the fact that the width of the dam site on the bed of the creek is 427 feet. He says the drainage area tributary to the Main River reservoir site is 150 square miles, ranging in elevation from 1,500 to 6,000 feet, with a mean rainfall of 30 inches in the drainage basins and a probable minimum of 7 inches. From the recent official surveys of the United States Geological Survey it has been definitely determined that the drainage area above this reservoir site is 71 square miles. The elevation of the bed of the canyon at the Main River dam site is 1,460 feet above sea level. This reservoir site is of such elevation as to command by gravity the present city tunnel line, which may be extended as the outlet for the Mono reservoir site (see pp. 40–41). The Main River reservoir site is owned by the Santa Barbara Water Company and is of some merit. If a tunnel is carried through the range this reservoir, commanding the present city tunnel in elevation, may ultimately be built, either by the water company or by its successors, thus materially adding to the supply for the district south of the mountains, which demands all the water possible to be obtained from Santa Ynez River.

JUNCAL SITE.

Purslow states that an observer was stationed at the Juncal, recording the rainfall and taking measurements of the flow of the stream during the "past winter," and that these records show that up to the date of writing the flow available for storage was upwards of 800 million gallons (2,455 acre-feet). This quantity includes the flow of Alder Creek basin (2.4 square miles), which he proposed to divert into the Juncal. It can not be definitely stated what space of time he meant to include within this period, but as his report bears date July 21, 1896, it is probable that these measurements extend from the 1st of November, 1895, to say the 1st of July, 1896. The rainfall during that winter was 13.77 inches at Santa Barbara, and his conclusion can not be accepted that this record may be taken as an approximate minimum for streams in the Santa Ynez Mountains, particularly as there was at Santa Barbara in the month of January a precipitation of 6.84 inches, which should, in all probability, have yielded a flood condition in the streams.

Purslow's surveys of the capacity of the Juncal reservoir site practically confirm those by Wright, already stated. The site is one of considerable merit, and possibly the dam should be built ultimately in connection with supplementing the storage capacity of the lower dams. The Gibraltar reservoir site, below the Mono on the trunk stream, however, offers a very much cheaper storage capacity and a much larger available supply. Purslow probably overestimates the underflow at the Main River site.

Purslow proposes using a riveted-steel pressure pipe line to divert the water to Santa Barbara; probably the life of this pipe line would not be more than fifteen years. His detailed estimate of the cost is $300,000 to obtain water from the Juncal. The dam which he proposes is to be 100 feet high, with a storage capacity of 1,023 million gallons. He estimates the minimum season's supply as 400 million gallons, and considers an annual draft of 600 million gallons (equal to 1,845 acre-feet) as the amount that might be obtained from the reservoir with that dam.

It is here estimated that the run-off from the Juncal would have been in minimum years as follows:

Run-off from Juncal reservoir.

	Acre-feet.
1869-70	603
1870-71	335
1897-98	0
1898-99	1,114
1899-1900	1,367

It must be remembered that these estimates are only approximations based upon observations on other streams somewhat similarly

situated and are not absolute. However, they are believed to be fair conclusions from the best available data, and, using them, we can not accept the conclusion that 1,845 acre-feet of water could annually be withdrawn from this reservoir site. This, however, does not condemn the site, if it is used in connection with the lower site to supplement the supply in dry years. It is believed that ultimately this reservoir may be constructed for this purpose, but it is not believed that it is wise to base a water supply for the city of Santa Barbara on it alone with its drainage basin of but 13 square miles.

REPORT OF R. B. CANFIELD, 1896.

On July 28, 1896, Mr. R. B. Canfield, president of the Santa Barbara Water Company, made a report supplemental to that of Purslow. Mr. Canfield's conclusions are also of interest because of his intimate and accurate knowledge of the water situation near Santa Barbara, on the south of the Santa Ynez Mountains. It must be remembered that the measurements of Wright to which he refers were made in a year of excessive stream flow.

Canfield says:

Mr. Wright found all the streams east of Santa Barbara, together with Mission Creek—9 streams in all—to be yielding daily 1,650,000 gallons, and the 15 creeks west of Mission Creek, to and including the Refugio, to be yielding daily 1,725,000 gallons, but he justly dismisses the idea of obtaining the needed supply from these sources as impracticable, partly owing to the expense of gathering and conveying the supply from so many points and over so long distances, and partly owing to the fact that all this water is claimed by riparian owners and individual water claimants and water companies organized to supply districts adjacent to some of the streams. It is well known that the demand for this water, especially in the neighborhood of this city, is beyond the capacity of all the streams to supply, and it is obvious that the expense of obtaining water from these sources would be prohibitive.

All the streams (excepting the flow of the Hot Springs) on the south slope of the range east of Mission Creek as far as Romero Canyon, 8 miles distant, were yielding when measured in the summer of 1889 a total daily flow of 500,000 gallons, while the creeks west of Mission Canyon to and including San Jose Creek, 7 miles distant, were yielding a total daily flow of only 475,000 gallons, notwithstanding the comparatively abundant rainfall of preceding seasons. Even though these were the minimum quantities to be obtained in the dry season from these streams (which is far from being the case) and it were possible to bring them all to Santa Barbara for the supply of the city, whether by surface diversion or by means of tunnels in their neighborhood, which would intercept the supplies and drain their channels, it would not be desirable to do so. Santa Barbara, if she could afford the expense necessary for the acquisition of these waters, could not afford the loss she would suffer by the destruction of the prosperity and beauty of her suburbs of Montecito and Goleta. The prosperity of Santa Barbara depends in a large measure upon that of the neighboring rural districts, as does theirs upon that of the city. To the extent to which the city deprives the suburbs of their natural water supply, it injures itself.

During the last spring borings were made under the direction of the city engineer west of the city in the hope of finding considerable underground currents, but without success. The subterranean waters in the eastern part of the ctiy are tapped by the wells of the Santa Barbara Water Company for the supply of its pumping plant; but all efforts to obtain the large additional supply which the city needs from these and other sources have

only tended to confirm the soundness of Mr. Wright's conclusion when he said: "I consider Santa Ynez River above the mouth of Blue Canyon to be not only an available source of supply, but the only source possible for the future supply of Santa Barbara with an abundance of good potable water."

Water is now sold in Santa Barbara at the rate of about 16 cents per thousand gallons to the city for street-sprinkling purposes (at the rate of $35,000 per year for 1 second-foot) and to private consumers at from 20 to 25 cents per thousand gallons, which are moderate rates as compared with those realized in some other cities in this State; and it is believed that although the development of the business in the future may justify some reduction of rates, an average rate of 15 cents per thousand gallons at least can be calculated upon. The city requires for its immediate needs at least 1,000,000 gallons of water daily, and its steady growth, soon to be accelerated by the completion of the railroad to San Francisco, will be constantly increasing this demand.

REPORT OF J. LINN MOYER, 1902.

MONO SITE.

On August 5, 1902, Mr. J. Linn Moyer, city engineer of Santa Barbara, made a report based on a reconnaissance through portions of the drainage basin of Santa Ynez River, particularly examining a new reservoir site suggested by Mr. Frank E. Kellogg, which the latter had observed on Mono Creek, the largest tributary of the upper portion of Santa Ynez River. Moyer made a favorable report on this situation, based on this reconnaissance, and made recommendations that further examinations be made. It was his judgment that the reservoir site, which is called the Mono site, was a good one and that the water supply available would be ample to meet the necessities of the city. Pls. III, *A*, and IV, *A*, *B*, show views of the Mono dam and reservoir sites. He recommended as follows:

1. That the exact elevation of the dam site be determined in order to ascertain whether or not the water could be conducted to the city tunnel.
2. That borings and excavations be made on the dam site to ascertain the depth of bed rock and the quality of same.
3. That a topographical survey be made of the reservoir basin in order to determine the height necessary to construct the dam, and also to determine the amount and location of land necessary to be purchased.
4. That an option be obtained on the land necessary to be purchased, as will be shown by the topographical survey.
5. That a chemical analysis be made of the waters of Mono Creek.
6. That the grade of the present city tunnel be reduced to the lowest possible rate.

Moyer found that a provision should be made to furnish a continuous supply of 1 million gallons per day in addition to the present flow of the tunnel in order to fully supply the entire present population of the city.

CONCLUSIONS DRAWN FROM FOREGOING REPORTS.

The foregoing reports have been reviewed in extenso because doing so brings these investigations up to date and also because they furnish a proper basis from which to start on the present investigations. It

A. MONO DAM SITE, LEFT ABUTMENT.

B. MONO CREEK RESERVOIR SITE.

View upstream from dam site.

will be seen that all of these distinguished authorities, each one of whom was intimately acquainted with the local situation, agree on the following vital points:

1. That the present supply of water for the city of Santa Barbara is inadequate and that unless it is increased the material development of the town will be seriously impeded.

2. That there is no adequate water supply within a reasonable limit of the city of Santa Barbara on the south side of the range from which the city could be supplied, and even if the water of such small streams as there are could be obtained it would be at a sacrifice of existing development.

3. That it is feasible and desirable to obtain an adequate supply of water from the drainage basin of Santa Ynez River, and that this can be done at a profit.

The writer has, therefore, taken up the consideration of the subject at this point and prepared estimates of cost, etc.

POPULATION AND CONSUMPTION OF WATER.

The population of Santa Barbara, according to the enumeration of the United States Census, is as follows:

Population of Santa Barbara.

1870	2,889
1880	3,460
1890	5,864
1900	6,587
1905 (estimated)	10,000
1910 (estimated)	12,500

The rate of growth of Santa Barbara was most rapid from 1880 to 1890, but it has always shown a substantial increase in population. Projecting it into the future we obtain the populations for 1905 and 1910 as stated above. It is believed by the other engineers, as well as the writer, that the development of the city is largely dependent upon an adequate water supply, not only in the city but upon the adjacent suburban property. If this is once obtained it may be expected that the population will more rapidly increase. Among people looking for future homes, especially in the West, the water question is considered one of prime importance in the selection of a residence. At present (1903) the municipal waterworks has some 709 taps through which water is served, and the Santa Barbara Water Company has about 900, making a total of 1,609 taps, serving a population of about 8,045 persons. The Gates system supplies 50 taps more.

In May, 1902, 301 meters of the municipal waterworks indicated 81 gallons per capita daily consumption. In June, 1902, 329 meters

indicated a consumption of 82 gallons per capita. In July, 1902, 369 meters indicated a consumption of 75.5 gallons per capita per day.

It will be seen that 55 per cent of the city's services are metered. It is estimated that 15 gallons per capita per day, not included in the above rate, are used in public buildings and in street sprinkling. It would probably be fair to say, using round numbers, that the present consumption of the city is 100 gallons per capita per day. This is a rather low rate of consumption for a California city, and in all probability the city would use to advantage more water if it were available at reasonable prices. The consumption in Los Angeles before meters were introduced, in the summer of 1901, was 306 gallons per capita per day. After the introduction of several thousand meters it is now 242 gallons per capita per day. The water commissioners of that city in their annual report for 1902 estimate that a reasonable consumption would be 150 gallons per capita per day for metered services. The city of San Jose, in 1890, was using 194 gallons per capita daily. Wright, in his report to the city, estimated on a consumption of 200 gallons, and Purslow considered that 130 gallons should be sufficient.

Considering the evidence in the case, it is believed that it is desirable, for the proper development of the city, improvements of lawns, gardens, etc., that 150 gallons daily, as an average for the year, should be used, and this has been adopted as a proper basis for this report.

In considering the storage of flood waters necessary to meet this situation, it has been estimated that 60 per cent of the water supply would be used in the six summer months, and 40 per cent in the six winter months. The question of evaporation from reservoirs is an important one in estimating on a storage system. It is believed that the annual evaporation from reservoirs in the basin of the Santa Ynez would be approximately 42 inches in depth, 67½ per cent of this occurring in the six summer months, and 32½ per cent in the six winter months. From a study of the monthly rainfall tables of precipitation occurring at Santa Barbara (see table 11) it appears that there would, in all probability, have been no material addition to the waters stored in any reservoirs in this locality from May 1, 1876, to December 1, 1877, a period of nineteen months. Again, between April 1, 1897, and October 1, 1898, or for a period of eighteen months, there would have been no material addition. It will be necessary, therefore, in order to prepare for the worst condition that will probably occur in the future, as judged by a record of thirty-six years' rainfall in the past, to construct reservoirs that will hold a supply of water for a period of nineteen months of continuous withdrawal without replenishment.

With a population of 10,000 persons in 1905, reasonably within sight and necessary to immediately prepare for, at 150 gallons per

day, there will be a consumption of 1,500,000 gallons daily. This amount of water withdrawn for a period of nineteen months will require 2,826[a] acre-feet for actual domestic uses. It is also necessary to provide for a loss by evaporation of about 692 acre-feet (for a reservoir of this size for nineteen months), or a total of 3,518 acre-feet for use and evaporation during the worst period of drought that the city will probably ever have to face.

Reducing it to a monthly withdrawal, there will be required for summer use 170 acre-feet, for summer evaporation about 45 acre-feet, and for summer use and evaporation 215 acre-feet.

From surveys that have been made of the reservoirs, described later in this report, it appears that a dam 85 feet high at the Mono site, impounding water to a depth of 75 feet, will give storage capacity for 3,880 acre-feet of water—enough to meet the above needs, even assuming the severe conclusions that no permanent supply can be relied upon from the tunnel, and that the municipality is to furnish all the water for the town. Similarly a dam 100 feet high at the Gibraltar site (see p. 55) would give an equal capacity and have tributary thereto a larger and better water supply.

NEAR-BY SUPPLIES.

The question of local water supply on the south side of the range was extensively discussed under the review of the reports of Wright, Purslow, and Canfield. Generally speaking, the amount now available for the city may be taken in average years as 300,000 gallons daily from Mission Creek, 300,000 gallons from the De la Guerra wells (statement by Purslow), and 350,000 gallons from the city tunnel, making 950,000 gallons to meet an estimated normal present demand of 1,200,000[b] gallons, or a deficit daily of 250,000 gallons.

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[a] One acre-foot is equivalent to 325,851 gallons.
[b] On basis of 150 gallons per day for 8,000 persons.

MISSION CREEK.

The following measurements of Mission Creek taken at various times, as stated, may be of interest in this connection:

TABLE 4.—*Discharge measurements on Mission Creek.*

Date.	Hydrographer.	Discharge in second-feet.[a]	Gallons per day.
1888.			
Jan. 15	A. Poett	0.93	605,594
24	do	2.80	18,200,000
Feb. 7	do	1.37	888,552
Mar. 16	do	2.23	1,452,000
July 26	do	.36	233,000
29	do	.28	184,747
1889.			
July 13	do	.43	282,609
17	do	.36	232,551
Aug.	G. F. Wright	.34	219,672
18	A. Poett	.21	137,052
Sept. 1	do	.32	206,821
1892.			
June 11	do	.36	232,673
1894.			
June 28	Flourney	.24	155,115
1900.			
May 10	do	.25	161,600
June 17	L. Moyer	.045	[b] 29,084

[a] One second-foot is equivalent to 50 miner's inches.
[b] Above diversion not on bed rock, 200 feet above dam.

TABLE 5.—*Measurements in Mission Canyon.*

[50 miner's inches=1 cubic foot per second.]

AT NOTCHED WEIR NEAR PORTAL OF PROPOSED NEW CITY MISSION TUNNEL.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Aug. 14	2.30 p. m.	R. L. North and J. Compton	6.367
15	8.30 a. m.	do	9.474
15	9 a. m.	do	8.817
15	9.30 a. m.	do	8.817
15	10 a. m.	do	8.689
15	10.30 a. m.	do	8.140

TABLE 5.—*Measurements in Mission Canyon*—Continued.

AT NOTCHED WEIR NEAR PORTAL OF PROPOSED NEW CITY MISSION TUNNEL—C't'd.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Aug. 15	11 a. m.	R. L. North and J. Compton	7.823
15	11.30 a. m.	do	7.832
15	12 m.	do	7.242
15	12.30 p. m.	do	6.959
15	1 p. m.	do	6.363
15	1.30 p. m.	do	6.109
15	2 p. m.	do	5.600
15	2.30 p. m.	do	5.359
15	3. p. m.	do	5.220
15	3.30 p. m.	do	4.851
15	4 p. m.	do	4.851
15	4.30 p. m.	do	4.851
15	5 p. m.	do	5.042
AT OLD MISSION DAM.			
1903.			
Aug. 22	6.30 p. m.	L. M. Hyde and R. L. North	0.909
23	9.10 a. m.	do	4.762
24	8.25 a. m.	L. M. Hyde, R. L. North, and G. D. Morrison	8.333
24	6.15 p. m.	do	6.896
25	7.45 a. m.	L. M. Hyde and R. L. North	10.000
27	7.15 a. m.	R. L. North, R. F. Wyckoff, and G. D. Morrison	10.000
AT NOTCHED WEIR AS ABOVE.			
1903.			
Aug. 27	8.30 a. m.	R. L. North and R. F. Wyckoff	9.080
27	9 a. m.	do	9.080
27	1 p. m.	do	7.070
27	1.30 p. m.	do	6.420
27	2 p. m.	do	5.750
27	2.30 p. m.	do	5.750
27	3 p. m.	do	5.410
27	3.30 p. m.	do	4.950
27	4 p. m.	do	4.990
27	4.30 p. m.	do	4.990
27	5 p. m.	do	4.810

TABLE 5.—*Measurements in Mission Canyon*—Continued.

AT OLD MISSION DAM.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Oct. 3	2.20 p. m.	J. L. Moyer, T. B. Curley, and D. Boyle	5.320

AT NOTCHED WEIR AS ABOVE.

1903.			
Oct. 19	8 a. m.	L. M. Hyde and C. M. Elliott	7.532
19	8.30 a. m.	do	7.356
19	9 a. m.	do	6.742
19	9.30 a. m.	do	6.314
19	10 a. m.	do	6.158
19	10.30 a. m.	do	6.003
19	11 a. m.	do	6.003
19	11.30 a. m.	do	5.803
19	12 m.	do	5.600
19	12.30 p. m.	do	5.317
19	1 p. m.	do	5.042
19	1.30 p. m.	do	4.810
19	2 p. m.	do	4.591
19	2.30 p. m.	C. M. Elliott	4.591
19	3 p. m.	do	4.378
19	3.30 p. m.	do	4.255
19	4 p. m.	do	4.169
19	4.30 p. m.	do	4.169
19	5 p. m.	do	3.970
Nov. 4	8.30 a. m.	G. D. Morrison	8.817
4	9 a. m.	do	8.753
4	9.30 a. m.	do	7.708
4	10 a. m.	do	7.416
4	10.30 a. m.	do	7.187
4	11 a. m.	do	6.852
4	11.30 a. m.	do	6.792
4	12 m.	do	6.579
4	12.30 p. m.	do	6.579
4	1 p. m.	do	6.261
4	1.30 p. m.	do	6.003
4	2 p. m.	do	6.003
4	2.30 p. m.	do	5.853
4	3 p. m.	do	5.903
4	3.30 p. m.	do	5.600

TABLE 5.—*Measurements in Mission Canyon*—Continued.

AT NOTCHED WEIR AS ABOVE—Continued.

Date.		Time.	Hydrographer.	Discharge in inches.
1903.				
Nov.	4	4 p. m.	G. D. Morrison	5.750
	4	4.30 p. m.	do	5.600
	16	8.30 a. m.	R. F. Wyckoff	8.689
	16	9 a. m.	do	7.945
	16	9.30 a. m.	do	7.299
	16	10 a. m.	do	7.242
	16	10.30 a. m.	do	6.595
	16	11 a. m.	do	6.792
	16	11.30 a. m.	do	6.687
	16	12 m.	do	6.420
	16	12.30 p. m.	do	6.314
	16	1 p. m.	do	6.314
	16	1.30 p. m.	do	5.853
	16	2 p. m.	do	5.600
	16	2.30 p. m.	do	5.269
	16	3 p. m.	do	5.131
	16	3.30 p. m.	do	4.950
	16	4 p. m.	do	4.851
	16	4.30 p. m.	do	4.680
	28	8.30 a. m.	R. L. North	6.370
	28	9 a. m.	do	6.690
	28	9.30 a. m.	do	6.000
	28	10 a. m.	do	5.900
	28	10.30 a. m.	do	5.650
	28	11 a. m.	do	5.650
	28	11.30 a. m.	do	5.510
	28	12 m.	do	5.510
	28	1 p. m.	do	5.040
	28	1.30 p. m.	do	4.850
	28	2 p. m.	do	4.720
	28	2.30 p. m.	do	4.680
	28	3 p. m.	do	4.680
	28	3.30 p. m.	do	4.340
	28	4 p. m.	do	4.300
	28	4.30 p. m.	do	4.130
	28	5 p. m.	do	3.970
Dec.	24	10.30 a. m.	G. D. Morrison	7.470
	24	11 a. m.	do	6.560
	24	11.30 a. m.	do	6.370

TABLE 5.—*Measurements in Mission Canyon*—Continued.

AT NOTCHED WEIR AS ABOVE—Continued.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Dec. 24	12 m.	G. D. Morrison	6.210
24	12.30 p. m.	do	6.160
24	1 p. m.	do	6.160
24	1.30 p. m.	do	5.950
24	2 p. m.	do	5.600
24	2.30 p. m.	do	5.460
24	3 p. m.	do	5.320
24	3.30 p. m.	do	5.080
24	4 p. m.	do	5.040
1904.			
Feb. 29	11.15 a. m.	L. M. Hyde	18.190
Mar. 14	3.30 p. m.	do	16.310

AT OLD MISSION DAM.

1904.			
Apr. 4		L. M. Hyde	16.670

TABLE 6.—*Measurements in Rattlesnake Canyon.*

AT NOTCHED WEIR ABOUT 200 FEET UPSTREAM FROM WHERE WATER IS DIVERTED FOR SANTA BARBARA WATER SUPPLY.

[50 miner's inches=1 cubic foot per second.]

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Aug. 17	8.30 a. m.	R. L. North and J. Compton	2.507
17	9 a. m.	do	2.596
17	9.30 a. m.	do	2.507
17	10 a. m.	do	2.216
17	10.30 a. m.	do	2.216
17	11 a. m.	do	2.216
17	11.30 a. m.	do	2.261
17	12 m.	do	2.261
17	12.30 p. m.	do	2.216
17	1 p. m.	do	2.261
17	1.30 p. m.	do	2.216
17	2 p. m.	do	2.216

TABLE 6.—*Measurements in Rattlesnake Canyon*—Continued.

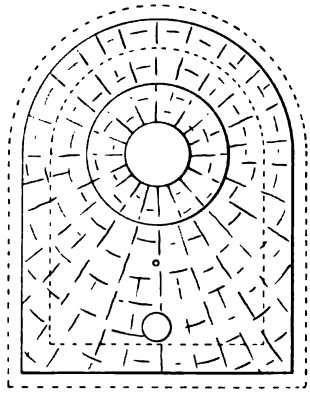
AT NOTCHED WEIR ABOUT 200 FEET UPSTREAM FROM WHERE WATER IS DIVERTED FOR SANTA BARBARA WATER SUPPLY—Continued.

Date.		Time.	Hydrographer.	Discharge in inches.
1903.				
Aug.	17	2.30 p. m.	R. L. North and J. Compton	2.132
	17	3 p. m.	do	2.080
	17	3.30 p. m.	do	2.080
	17	4 p. m.	do	2.080
	17	4.30 p. m.	do	2.080
	17	5 p. m.	do	2.216
Oct.	3	3.45 p. m.	J. L. Moyer, T. B. Curley, and D. Boyle	2.261
	19	8.30 a. m.	R. L. North	1.772
	19	9 a. m.	do	1.627
	19	9.30 a. m.	do	1.492
	19	10 a. m.	do	1.582
	19	10.30 a. m.	do	1.471
	19	11 a. m.	do	1.582
	19	11.30 a. m.	do	1.582
	19	12 m.	do	1.302
	19	12.30 p. m.	do	1.448
	19	1 p. m.	do	1.403
	19	1.30 p. m.	do	1.242
	19	2 p. m.	do	1.471
	19	2.30 p. m.	do	1.302
	19	3 p. m.	do	1.262
	19	3.30 p. m.	do	1.403
	19	4 p. m.	do	1.514
	19	4.30 p. m.	do	1.448
	19	5 p. m.	do	1.514
Nov.	3	9.30 a. m.	G. D. Morrison	1.871
	3	10 a. m.	do	1.847
	3	10.30 a. m.	do	1.897
	3	11 a. m.	do	1.822
	3	11.30 a. m.	do	1.797
	3	12 m.	do	1.797
	3	12.30 p. m.	do	1.746
	3	1 p. m.	do	1.772
	3	1.30 p. m.	do	1.772
	3	2 p. m.	do	1.651
	3	2.30 p. m.	do	1.746
	3	3 p. m.	do	1.722
	3	3.30 p. m.	do	1.722
	3	4 p. m.	do	1.772

TABLE 6.—*Measurements in Rattlesnake Canyon*—Continued.

AT NOTCHED WEIR ABOUT 200 FEET UPSTREAM FROM WHERE WATER IS DIVERTED FOR SANTA BARBARA WATER SUPPLY—Continued.

Date.		Time.	Hydrographer.	Discharge in inches.
1902.				
Nov.	3	4.30 p. m.	G. D. Morrison	1.772
	15	9 a. m.	R. F. Wyckoff	2.360
	15	9.30 a. m.	do	2.360
	15	10 a. m.	do	2.272
	15	10.30 a. m.	do	2.160
	15	11 a. m.	do	2.160
	15	11.30 a. m.	do	2.132
	15	12 m.	do	2.132
	15	12.30 p. m.	do	2.080
	15	1 p. m.	do	2.080
	15	1.30 p. m.	do	2.080
	15	2 p. m.	do	1.972
	15	2.30 p. m.	do	2.051
	15	3 p. m.	do	2.080
	15	3.30 p. m.	do	2.051
	15	4 p. m.	do	2.051
	15	4.30 p. m.	do	2.080
	28	8.30 a. m.	G. D. Morrison	2.160
	28	9 a. m.	do	2.110
	28	9.30 a. m.	do	2.030
	28	10 a. m.	do	2.070
	28	10.30 a. m.	do	2.000
	28	11 a. m.	do	1.970
	28	11.30 a. m.	do	1.970
	28	12 m.	do	1.900
	28	12.30 p. m.	do	1.950
	28	1 p. m.	do	1.900
	28	1.30 p. m.	do	1.850
	28	2 p. m.	do	1.820
	28	2.30 p. m.	do	1.820
	28	3 p. m.	do	1.770
	28	3.30 p. m.	do	1.720
	28	4 p. m.	do	1.750
Dec.	23	9 a. m.	do	2.510
	23	9.30 a. m.	do	2.510
	23	10 a. m.	do	2.480
	23	10.30 a. m.	do	2.480
	23	11 a. m.	do	2.390
	23	11.30 a. m.	do	2.360



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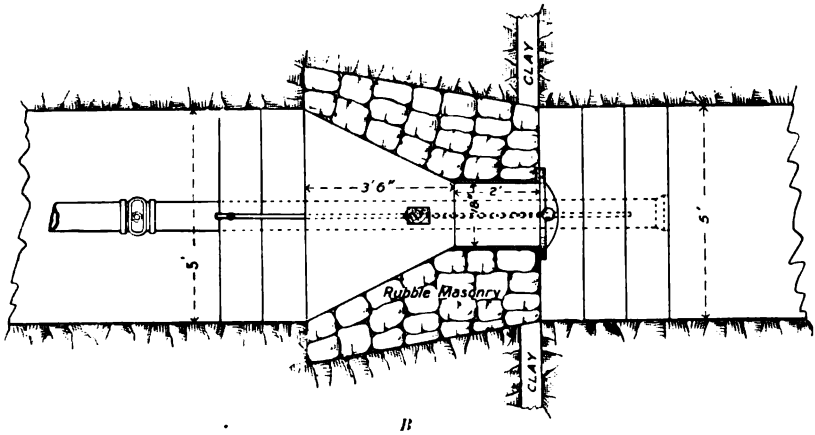

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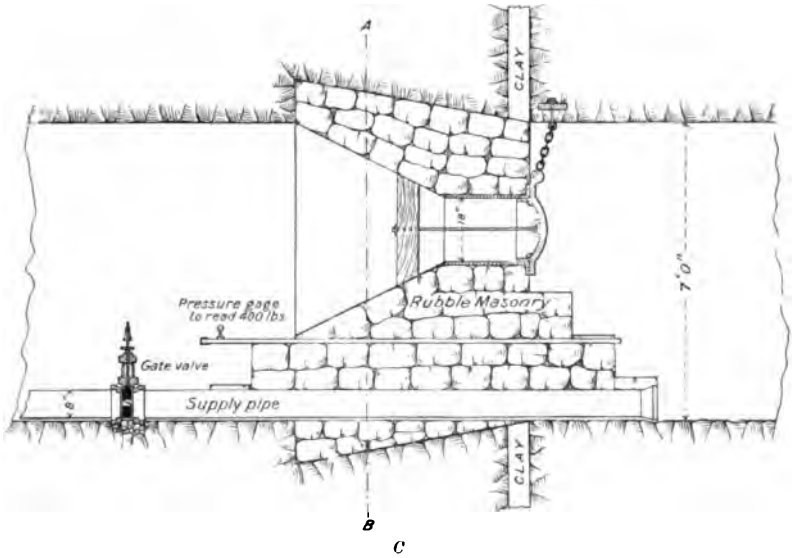

C

BULKHEAD AND DISCHARGE PIPES IN OLD CITY TUNNEL, COLD SPRINGS CANYON.

A, End view; *B*, plan; *C*, longitudinal section.

TABLE 6.—*Measurements in Rattlesnake Canyon*—Continued.

AT NOTCHED WEIR ABOUT 200 FEET UPSTREAM FROM WHERE WATER IS DIVERTED FOR SANTA BARBARA WATER SUPPLY—Continued.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Dec. 23	12 m.	G. D. Morrison	2.360
23	12.30 p. m.	do	2.270
23	1 p. m.	do	2.270
23	1.30 p. m.	do	2.330
23	2 p. m.	do	2.360
23	2.30 p. m.	do	2.360
23	3 p. m.	do	2.360
23	3.30 p. m.	do	2.390
23	4 p. m.	do	2.450
1904.			
Apr. 7	1.45 p. m.	L. M. Hyde	12.460

DE LA GUERRA WELLS.

At the De la Guerra pumping station there are seven cased wells from 200 to 700 feet deep. These discharge into a concrete well 25 feet in diameter and 30 feet deep, having a capacity of 110,160 gallons. This well fills during the night and is pumped out during the day. If the wells are considered as discharging as much during the day as they do during the night when the tank is filling, their flow at present is about 220,000 gallons daily and is (in 1903) decreasing. As the pumps run more than twelve hours each day the output is correspondingly greater. There is installed at this station one Prescott pump of 1½ million gallons nominal capacity and one Worthington pump of 1 million gallons capacity daily. The pumps discharge directly into the city mains and work against a pressure head of from 100 to 120 pounds. Mr. Wright states that in August, 1889, a six-day test of these wells indicated a capacity of 600,000 gallons daily. It is stated that these wells afterwards failed and that deeper wells were then sunk, from which the present supply is now obtained.

CITY TUNNEL.

In the month of January, 1896, the city of Santa Barbara started a tunnel for the development of water in sec. 36, T. 5 N., R. 26 W., San Bernardino meridian. The tunnel has been successful in this particular and has been of inestimable service to the city in sustaining it through the period of intense drought of the last few years. The tunnel is 7 feet high and 5 feet wide at the base. The elevation of

the portal is approximately 1,400 feet above sea level, and it was driven for the first 4,800 feet of its length on a grade of 1 foot in 100. The purpose in running the tunnel at first was solely to develop water and not with the intention of extending it on through the mountains. It will be noted from the table of discharge that during its construction the discharge was surprisingly constant, irrespective of length. Enough water is thus obtained for a number of consumers, but not enough to supply a large town or city. The amount of water which was extracted from the mountain was sufficient to pay for the cost of the excavation. It is quite possible that in years of ordinary rainfall the unregulated flow of water from the tunnel would have been more constant, but the years of construction were ones of unusual drought. However, from the fact that the water supply has not been materially increased by lengthening the tunnel, and that the flow of the water pays for the cost of the work, it has been a natural and logical sequence that the city should contemplate the extension of this or some other tunnel entirely through the Coast Range into the drainage basin of the Santa Ynez in order to make available the water of this large mountainous area. The tunnel work has been carried on with intelligence, the power from the water coming therefrom being conducted through pressure pipes and used for the running of drills for the excavation work.

COST OF TUNNEL.

As a guide to what the city may expect in the future, the expense of doing this tunnel work is of interest. It will be noted that there has been variation in the cost, owing to local conditions of the labor market, etc. The city has installed the machinery necessary for doing the work, and the contractor has furnished the labor and material necessary for its prosecution at the rate named in the table.

TABLE 7.—*Cost of labor and material in driving city tunnel.*

Distance excavated.	Price per foot.	Distance excavated.	Price per foot.
Feet.		*Feet.*	
0 to 1,000	$5.50	1,642 to 1,750	.....
1,000 to 1,146	7.50	1,750 to 1,786½	$13.76
1,146 to 1,202	8.73	1,786½ to 2,286	9.30
1,202 to 1,276½	7.58	2,286 to 2,572	10.00
1,276½ to 1,363½	6.89	2,572 to 3,072	10.75
1,363½ to 1,434½	8.25	3,072 to 3,572	10.48
1,434½ to 1,500	9.00	3,572 to 4,072	9.17
1,500 to 1,582	.....	4,072 to 5,072	9.00
1,582 to 1,642	9.00		

DISCHARGE OF TUNNEL.

The tunnel is run in a sandstone and shale formation characteristic of the Coast Range, the rock being considerably broken and somewhat stratified. As the work progresses many crevices and cavities in the rock filled with water, probably from rainfall, are found, and as the tunnel cuts the various lines of cleavage these underground reservoirs are tapped. The actual rock is not of a very porous nature and in itself does not yield much water, but it is believed that these cavities will be refilled, at least in part, by subsequent rains and that a material amount of water can be permanently withdrawn from the tunnel. If the city does obtain a supply therefrom permanently there will be just that much more water at its disposal, and there certainly is a market for it all, either in the city or on adjoining agricultural lands.

The water is led from the tunnel to two city reservoirs, each with a capacity of 1,600,000 gallons, situated at an elevation of 350 feet above the city datum plane.

The power now available at the tunnel for driving the drills and blowers is inadequate for its continuation. Generally speaking, it requires from 10 to 12 horsepower to run each air drill, not including the power for the blowers for ventilation.

In order to regulate the flow of water from this tunnel after the last contract was finished, to the 5,000-foot point from the heading, a bulkhead was designed by the author and placed in the tunnel about 800 feet from the portal. During the winter of 1902–3 there was a fair amount of rainfall and the streams were capable during that time of meeting the demands of the city. As soon as the bulkhead could be closed this was done—about July 1, 1903.

Because of the fissured condition of the rock in the tunnel it was not feasible at the point where the bulkhead was first placed to completely close the supply from the heading, as springs occurred below the bulkhead toward the portal, flowing in considerable volume. However, the pressure ran up to 49 pounds to the square inch on July 25, as recorded by the pressure gage placed in the discharge pipe, indicating an accumulated head of water back of the bulkhead of 114 feet. This shows that the tunnel was developed into a storage reservoir. The gate valve in the bulkhead was gradually opened as the season progessed, and the supply maintained a flow of from 24 to 33 miner's inches during the remainder of the summer. On October 17, when the valve was completely opened and the pressure had been reduced to zero, the flow had fallen to 24 miner's inches. This was sufficient to carry the city through the summer successfully.

During the winter of 1903–4 a new bulkhead was placed at a point in the tunnel where a heavy clay seam occurs in the rock. This new bulkhead was more effective than the first one constructed in

holding back the water. It is hoped that this will form an impervious barrier against the passage of the ground water, thus enabling the tunnel to accumulate a high head of water.[a]

Table 8a shows the variation in volume discharged from the tunnel, as well as the pressure in pounds per square inch, as the season advances.

TABLE 8.—*Flow of water from city tunnel.*

Date.	Length of tunnel in feet.	Flow in miner's inches.[b]	Flow in gallons per day.
1900.			
May 1	2,952	25.00	323,125
July 26	3,078	19.00	245,575
August 1	3,103	19.00	245,575
October 27	3,267	20.00	258,500
November 4	3,280	25.00	323,125
1901.			
January 9	3,393	38.00	491,150
February 1	3,448	50.00	646,250
February 28	3,561	63.33	818,583
April 1	3,614	55.00	710,875
May 1	3,680	45.00	581,625
June 1	3,740	45.00	581,625
July 1	3,792	[c]35.00	452,375
August 1	3,865	30.00	387,750
1902.			
February 4	4,182	30.00	387,750
March 4	4,256	30.00	387,750
March 31	4,309	33.00	426,525
April 29	4,367	30.00	387,750
June 7	4,509	24.00	310,200
July 25	4,560	25.50	329,588
August 4	4,578	27.75	358,669
September 2	4,647	30.30	391,625
December 1	4,832	30.00	387,750

[a] 24.59 inches of rain fell at Montecito between September 24, 1904, and March 3, 1905, and the pressure on the tunnel bulkhead had increased to 80 pounds per square inch.
[b] 50 miner's inches are equivalent to 1 second-foot, and 1 miner's inch to 12,925 gallons per day.
[c] Estimated.

TABLE 8a.—*Daily mean head over 18-inch weir, and discharge, of Santa Barbara tunnel, 1903.*[a]

Day	January.				February.				March.				April.			
	Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.		
		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.
1	0.191	0.405	20.25	261,758	0.210	0.469	23.45	303,122	0.271	0.679	33.95	438.848	0.292	0.756	37.80	488,614
2	.193	.412	20.60	266,282	.214	.482	24.10	311,524	.270	.675	33.75	436,263	.326	.890	44.50	575,220
3	.196	.418	20.90	270,160	.218	.493	24.65	318,633	.270	.675	33.75	436,263	.370	1.068	53.40	690,264
4	.195	.418	20.90	270,160	.217	.489	24.45	316,048	.269	.971	33.55	433,677	.371	1.072	53.60	692,850
5	.195	.418	20.90	270,160	.214	.482	24.10	311,524	.269	.671	33.55	433,677	.369	1.064	53.20	687,679
6	.195	.418	20.90	270,160	.210	.469	23.45	303,122	.268	.668	33.40	431,738	.365	1.046	52.30	676,045
7	.195	.418	20.90	270,160	.214	.482	24.10	311,524	.268	.668	33.40	431,738	.361	1.032	51.60	666,997
8	.195	.418	20.90	270,160	.220	.500	25.00	323,158	.267	.664	33.20	429,153	.357	1.016	50.80	656,656
9	.195	.418	20.90	270,160	.227	.524	26.20	338,669	.267	.664	33.20	429,153	.354	1.003	50.15	648,254
10	.195	.418	20.90	270,160	.235	.553	27.65	357,412	.266	.660	33.00	426,568	.352	.995	49.75	643,083
11	.195	.418	20.90	270,160	.234	.549	27.45	354,827	.266	.660	33.00	426,568	.350	.986	49.30	637,267
12	.200	.435	21.75	281,147	.231	.538	26.90	347,717	.265	.656	32.80	423,983	.346	.969	48.45	626,279
13	.204	.448	22.40	289,549	.228	.528	26.40	341,254	.265	.656	32.80	423,983	.344	.961	48.05	621,109
14	.200	.435	21.75	281,147	.232	.542	27.10	350,303	.264	.653	32.65	422,044	.342	.954	47.70	616,585
15	.200	.435	21.75	281,147	.238	.560	28.00	361,936	.264	.653	32.65	422,044	.340	.947	47.35	612,060
16	.200	.435	21.75	281,147	.246	.589	29.45	380,680	.263	.650	32.50	420,105	.338	.940	47.00	607,536
17	.200	.435	21.75	281,147	.254	.618	30.90	399,423	.263	.650	32.50	420,105	.341	.944	47.20	610,121
18	.200	.435	21.75	281,147	.247	.592	29.60	382,618	.264	.653	32.65	422,044	.350	.986	49.30	637,267
19	.202	.442	22.10	285,671	.240	.567	28.35	366,461	.264	.653	32.65	422,044	.350	.986	49.30	637,267
20	.204	.448	22.40	289,549	.240	.567	28.35	366,461	.266	.660	33.00	426,568	.350	.986	49.30	637,267
21	.205	.452	22.60	292,134	.249	.600	30.00	387,789	.266	.660	33.00	426,568	.350	.986	49.30	637,267
22	.205	.452	22.60	292,134	.256	.626	31.30	404,593	.265	.656	32.80	423,983	.350	.986	49.30	637,267
23	.205	.452	22.60	292,134	.257	.630	31.50	407,178	.265	.656	32.80	423,983	.350	.986	49.30	637,267
24	.205	.452	22.60	292,134	.261	.645	32.25	416,873	.263	.650	32.50	420,105	.350	.986	49.30	637,267
25	.205	.452	22.60	292,134	.259	.637	31.85	411,703	.262	.647	32.35	418,166	.350	.986	49.30	637,267
26	.207	.459	22.95	296,659	.258	.633	31.65	409,117	.262	.647	32.35	418,166	.350	.986	49.30	637,267
27	.210	.469	23.45	303,122	.257	.630	31.50	407,178	.262	.647	32.35	418,166	.349	.982	49.10	634,681
28	.214	.482	24.10	311,524	.265	.656	32.80	423,983	.266	.660	33.00	426,568	.351	.990	49.50	639,852
29	.212	.476	23.80	307,646	.....	.....	.....	.....	.268	.668	33.40	431,738	.350	.986	49.30	637,267
30	.209	.465	23.25	300,536	.....	.....	.....	.....	.269	.671	33.55	433,677	.348	.978	48.90	632,096
31	.207	.459	22.95	296,659	.....	.....	.....	.....	.278	.706	35.30	456,298	.....	.....	.....	.....
Total	.....	.....	.....	8,787,947	.....	.....	.....	10,114,830	.....	.....	.....	13,253,984	.....	.....	.....	-19,035,918
Average	.201	.439	21.93	283,482	.237	.559	27.95	361,244	.266	.662	33.08	427,548	.349	.982	49.09	634,531

[a] By the closing of the bulkhead during the spring of 1904 the water was again impounded in the tunnel and the flow regulated therefrom so as to sustain a fairly constant flow throughout the summer of 1904. Owing to the drought this was the main water supply of the city during that period.

TABLE 8a.—*Daily mean head over 18-inch weir, and discharge, of Santa Barbara tunnel, 1903*—Continued.

Day.	May.				June.				July.				August.			
	Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.		
		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.
1	0.354	1.003	50.15	648,254	0.302	0.796	39.80	514,467	0.326	0.890	44.50	575,220	0.307	0.816	40.80	527,393
2	.360	1.029	51.45	665,058	.300	.788	39.40	509,269	.326	.890	44.50	575,220	.318	.857	42.85	553,892
3	.362	1.036	51.80	669,582	.301	.792	39.60	511,881	.326	.890	44.50	575,220	.320	.865	43.25	559,062
4	.362	1.036	51.80	669,582	.302	.796	39.80	514,467	.326	.890	44.50	575,220	.326	.890	44.50	575,220
5	.358	1.021	51.05	659,888	.302	.796	39.80	514,467	.326	.890	44.50	575,220	.329	.902	45.10	582,976
6	.360	1.029	51.45	665,058	.300	.788	39.40	509,269	.300	.788	39.40	509,296	.329	.902	45.10	582,976
7	.363	1.039	51.95	671,521	.300	.788	39.40	509,269	.239	.563	28.15	363,875	.336	.932	46.60	602,366
8	.366	1.050	52.50	678,631	.300	.788	39.40	509,269	.225	.518	25.90	334,791	.333	.919	45.95	593,963
9	.366	1.050	52.50	678,631	.298	.780	39.00	504,126	.220	.500	25.00	323,158	.322	.873	43.65	564,233
10	.360	1.029	51.45	665,058	.292	.756	37.80	488,614	.220	.500	25.00	323,158	.321	.869	43.45	561,648
11	.360	1.029	51.45	665,058	.293	.760	38.00	491,199	.219	.496	24.80	320,572	.328	.898	44.90	580,391
12	.360	1.029	51.45	665,058	.278	.706	35.30	456,298	.219	.496	24.80	320,572	.290	.748	37.40	483,444
13	.358	1.021	51.05	659,888	.306	.812	40.60	524,808	.220	.500	25.00	323,158	.249	.600	30.00	387,789
14	.308	.820	41.00	529,978	.307	.816	40.80	527,393	.220	.500	25.00	323,158	.273	.687	34.35	444,018
15	.223	.510	25.50	329,621	.308	.820	41.00	529,978	.234	.549	27.45	354,827	.275	.694	34.70	448,543
16	.258	.633	31.65	409,117	.310	.828	41.40	535,149	.270	.675	33.75	436,263	.277	.702	35.10	453,713
17	.300	.788	39.40	509,296	.311	.832	41.60	537,734	.292	.756	37.80	488,614	.276	.698	34.90	451,128
18	.301	.792	39.60	511,881	.312	.836	41.80	540,319	.268	.668	33.40	431,738	.275	.694	34.70	448,543
19	.302	.796	39.80	514,467	.313	.840	42.00	542,905	.254	.618	30.90	399,423	.274	.690	34.50	445,957
20	.303	.800	40.00	517,052	.314	.843	42.15	544,844	.258	.633	31.65	409,117	.273	.687	34.35	444,018
21	.304	.804	40.20	519,637	.315	.847	42.35	547,429	.272	.683	34.15	441,433	.270	.675	33.75	436,263
22	.305	.808	40.40	522,223	.316	.850	42.50	549,368	.271	.679	33.95	438,848	.300	.788	39.40	509,296
23	.307	.816	40.80	527,393	.317	.853	42.65	551,307	.267	.664	33.20	429,153	.324	.881	44.05	569,404
24	.308	.820	41.00	529,978	.318	.857	42.85	553,892	.272	.683	34.15	441,433	.254	.618	30.90	399,423
25	.307	.816	40.80	527,393	.319	.861	43.05	556,477	.275	.694	34.70	448,543	.134	.241	12.05	155,762
26	.307	.816	40.80	527,393	.320	.865	43.25	559,062	.274	.690	34.50	445,957	.194	.415	20.75	268,221
27	.306	.812	40.60	524,808	.321	.869	43.45	561,648	.271	.679	33.95	438,848	.277	.702	35.10	453,713
28	.306	.812	40.60	524,808	.322	.873	43.65	564,233	.276	.698	34.90	451,128	.278	.706	35.30	456,298
29	.305	.808	40.40	522,223	.323	.877	43.85	566,818	.264	.653	32.65	422,044	.260	.641	32.05	414,288
30	.303	.800	40.00	517,052	.325	.885	44.25	571,989	.260	.641	32.05	414,288	.258	.633	31.65	409,117
31	.303	.800	40.00	517,052	.....	.....	.....	.....	.274	.690	34.50	445,957	.256	.626	31.30	404,593
Total	.....	.....	.....	17,742,639	.....	.....	.....	15,898,056	.....	.....	.....	13,355,452	.....	.....	.....	14,767,561
Average	.324	.886	44.28	572,342	.308	.820	41.00	529,935	.267	.667	33.33	430,821	.285	.737	36.85	476,373

Day.	September.				October.				November.				December.			
	Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.		
		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.
1	0.254	0.618	30.90	399,423	0.240	0.567	28.35	366,461	0.228	0.528	26.40	341,254	0.223	0.510	25.50	329,621
2	.252	.612	30.60	395,545	.238	.561	28.05	362,583	.228	.528	26.40	341,254	.222	.507	25.35	327,682
3	.250	.604	30.20	390,374	.260	.641	32.05	414,288	.228	.528	26.40	341,254	.222	.507	25.35	327,682
4	.250	.604	30.20	390,374	.276	.698	34.90	451,128	.228	.528	26.40	341,254	.222	.507	25.35	327,682
5	.248	.596	29.80	385,204	.260	.641	32.05	414,288	.228	.528	26.40	341,254	.222	.507	25:35	327,682
6	.248	.596	29.80	385,204	.250	.604	30.20	390,374	.228	.528	26.40	341,254	.222	.507	25.35	327,682
7	.248	.596	29.80	385,204	.244	.581	29.05	375,509	.228	.528	26.40	341,254	.222	.507	25.35	327,682
8	.248	.596	29.80	385,204	.241	.570	28.50	368,400	.228	.528	26.40	341,254	.222	.507	25.35	327,682
9	.248	.596	29.80	385,204	.240	.567	28.35	366,461	.228	.528	26.40	341,254	.222	.507	25.35	327,682
10	.248	.596	29.80	385,204	.260	.641	32.05	414,288	.227	.524	26.20	338,669	.222	.507	25.35	327,682
11	.248	.596	29.80	385,204	.244	.581	29.05	375,509	.227	.524	26.20	338,669	.222	.507	25.35	327,682
12	.248	.596	29.80	385,204	.241	.570	28.50	368,400	.227	.524	26.20	338,669	.222	.507	25.35	327,682
13	.248	.596	29.80	385,204	.240	.567	28.35	366,461	.227	.524	26.20	338,669	.222	.507	25.35	327,682
14	.247	.592	29.80	382,618	.239	.563	28.15	363,875	.227	.524	26.20	338,669	.222	.507	25.35	327,682
15	.246	.589	29.45	380,680	.238	.560	28.00	361,936	.227	.524	26.20	338,669	.222	.507	25.35	327,682
16	.246	.589	29.45	380,680	.236	.556	27.80	359,351	.227	.524	26.20	338,669	.221	.503	25.15	325,096
17	.245	.585	29.25	378,094	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.221	.503	25.15	325,096
18	.244	.581	29.05	375,509	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.221	.503	25.15	325,096
19	.243	.577	28.85	372,924	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.221	.503	25.15	325,096
20	.242	.574	28.70	370,985	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.220	.500	25.00	323,158
21	.240	.567	28.35	366,461	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.220	.500	25.00	323,158
22	.269	.671	33.55	433,677	.236	.556	27.80	359,351	.227	.524	26.20	338,669	.220	.500	25.00	323,158
23	.262	.647	32.35	418,166	.236	.556	27.80	359,351	.226	.520	26.00	336,084	.220	.500	25.00	323,158
24	.260	.641	32.05	414,288	.236	.556	27.80	359,351	.225	.517	25.85	334,145	.220	.500	25.00	323,158
25	.259	.637	31.85	411,703	.234	.549	27.45	354,827	.225	.517	25.85	334,145	.220	.500	25.00	323,158
26	.221	.503	25.15	325,096	.232	.542	27.10	350,303	.224	.514	25.70	332,206	.220	.500	25.00	323,158
27	.240	.567	28.35	366,461	.232	.542	27.10	350,303	.224	.514	25.70	332,206	.220	.500	25.00	323,158
28	.240	.567	28.35	366,461	.232	.542	27.10	350,303	.224	.514	25.70	332,206	.219	.496	24.80	320,572
29	.240	.567	28.35	366,461	.232	.542	27.10	350,303	.224	.514	25.70	332,206	.219	.496	24.80	320,572
30	.240	.567	28.35	366,461	.232	.542	27.10	350,303	.223	.510	25.50	329,621	.218	.493	24.65	318,633
31	.....	.....	.....	.....	.230	.535	26.75	345,779	.....	.....	.....	.....	.218	.493	24.65	318,633
Total	.....	.....	.....	11,519,277	.....	.....	.....	11,436,546	.....	.....	.....	10,136,802	.....	.....	.....	10,081,227
Average	.247	.594	29.70	383,976	.241	.571	28.55	368,921	.227	.523	26.15	337,893	.221	.503	25.15	325,201

TOTAL NEAR-BY SUPPLY.

Reviewing these measurements we have a probable summer minimum water supply available for the city from local sources approximately as follows:

Local water supply of Santa Barbara.

	Gals. per day.
Minimum from Mission Creek	100,000
Minimum from De la Guerra wells	300,000
Minimum from city tunnel	300,000
Total	700,000

as against an estimated normal summer demand of 1,200,000[a] gallons per day, or an estimated normal deficit daily of 500,000 gallons.

There is not as much water now being used in the city for beautifying lawns and gardens as would be so applied if a more abundant supply were available. From the above it is evident that the city should take immediate steps toward increasing its water supply.

DISTANT SUPPLIES.

EXTENSION OF CITY TUNNEL.

With a view to the extension of the present city tunnel through the Santa Ynez Range to tap the waters of Santa Ynez River, a system of triangulation was carried across the mountains from Santa Barbara to the Mono reservoir site by Homer Hamlin and W. B. Clapp, of the Geological Survey. The base line of this system was measured on State street, Santa Barbara, between Boulevard and Pedregosa streets, and the most northerly point was the high peaks south of the Mono reservoir site. The base line, which was carefully measured with a 300-foot steel tape under a uniform tension of 25 pounds and corrected for temperature, was 9,753.7 feet long. The angles were measured with a Berger transit No. 1b, circles 6¼ inches in diameter. Eleven principal triangulation stations and 5 secondary stations were occupied, the secondary triangulation being necessary to reach the south portal of the present city tunnel, which is situated in a deep canyon. Angles were repeated three times and measured in six sets of two each. The triangles closed for angles within 0° 0′ 0″ to 0° 0′ 10″. The angle adjustments were made by distributing the difference proportionally as probable error due to weather conditions. The traverse of the outside boundary of the triangulation system closed as follows: N., 45,343.66; S., 45,343.63; E., 28,397.22; W., 28,397.15.

[a] On basis of 150 gallons per day for 8,000 persons.

The north portal of the extended tunnel, as projected, was fixed by a station on the cliff on the south side of Santa Ynez River. The north portal bears N. 26° 38′ 18″ E., and is 18,842.06 feet distant from the south portal of the present city tunnel. This tunnel was 4,895 feet long on January 26, and if an angle is made in it at 5,960 feet it will be necessary to drive 15,006 feet to reach Santa Ynez River and finish the work. By doing so a saving of 1,475 feet will be made; otherwise the tunnel must have a length of 21,376 feet to get through the range. It is probable, however, that a still more favorable location may be found.

From the surveys that have been made during the last season in the drainage basin of Santa Ynez River, the elevation of the south portal of the city tunnel in Cold Spring Canyon was taken at 1,393.06 feet; the rise on grade from the portal to station 48, at the projected north portal, is 49.02 feet. The total length of excavation necessary to complete this tunnel through the range is 15,066 feet. At a grade of 0.1 per cent this will require 15 feet more to be consumed in tunnel grade, making the elevation of the north portal of the tunnel 1,457.18 feet. The elevation of Santa Ynez River bed opposite is 1,425 feet. The necessary grade to be consumed from the north portal of the tunnel to the Mono reservoir site would be about 4 feet, making the elevation of the grade at the Mono reservoir site 1,461.18 feet. The elevation of the bed of the creek at the Mono site is 1,440 feet, so that the conduit grade would be 21.18 feet above the bed of the creek at that point, but the capacity of the lower portion of a reservoir site is always very small, and there would be a loss of but 1 per cent in the capacity of a 100-foot dam at the Mono with the elevations given.

CONSTRUCTION OF NEW TUNNEL.

In the old city tunnel in Cold Spring Canyon several angles occur in the alignment. The grade of the tunnel is also not satisfactory, in that it is too high to reach the bed of the stream at the mouth of the Mono at the elevation of the creek. While the old city tunnel could be used in this regard, it is not considered the best site for a tunnel, in view of subsequent surveys and investigations. Moreover, the old tunnel is delivering a very substantial water supply under existing conditions, particularly since being regulated by the bulkhead described above, and as a new tunnel can be obtained at a satisfactory elevation, which will develop a new water supply and in addition command certain reservoir sites on lower portions of the stream below the mouth of the Mono, it is desirable to adopt the second location. After the first investigations made in the basin of Santa Ynez River, which included the survey of the Mono reservoir site, the Main River reservoir site, and an inspection of

sites higher on the stream, a much better site situated on the main stream below the mouth of the Mono was found. This is called the Gibraltar reservoir site and is described more fully below.

The capacity of the Gibraltar reservoir so not quite so great as that of the Mono, but is very satisfactory, while the dam site is very much better, and the tributary drainage area a great deal larger, including not only that of the Mono, but also that of the Santa Ynez above the Mono, and 17 square miles of Main Canyon below. For the season of 1902–3 the measured flow at the Mono dam site was 8,934 acre-feet, at the Santa Ynez above the Mono 9,898 acre-feet, and for the Santa Ynez at the Gibraltar reservoir site 21,202 acre-feet. As the water supply is the most essential feature of the entire enterprise, no hesitation is felt in recommending that the tunnel line which is to be run through the range should be made to command the Gibraltar reservoir site. This would be impossible with the old city tunnel, on account of its high elevation in Cold Spring Canyon. Moreover, the combined cost of the Gibraltar dam and of a tunnel to it from Mission Canyon is less than the combined cost for completing the old city tunnel and building the Mono dam.

For the reasons given above, the triangulation which had been made for the old city tunnel was extended so as to cover the site of a possible new tunnel line from Mission Canyon to the Gibraltar dam site, which would be 19,560 feet long and would run through the same general formation at right angles to the line of the strike of the rock, passing under portions of Mission Creek.

AGREEMENT WITH WATER COMPANY.

An agreement was made with the Santa Barbara Water Company for rights of way for this new tunnel line. This company has for years been acquiring lands along Mission Canyon in order to protect its water supply, which comes mostly therefrom. The company naturally felt that the running of the tunnel beneath Mission Creek might affect its supply of water from the creek and insisted on being secured against such a contingency. In consequence the Santa Barbara water commissioners entered into a contract with the company by which the city agrees to maintain the supply of the company at 14 inches from July 1 to December 31 and at 22 inches from January 1 to June 30, supplying the water from the tunnel in case it is not flowing naturally in the creek, provided that amount can be supplied from the tunnel alone and irrespective of water subsequently obtained from storage reservoirs. In return the Santa Barbara Water Company gives the city rights of way over all its lands for wagon roads, tunnels, pipe lines, etc., and agrees not to run any tunnels on its lands in the vicinity of the city tunnel. This contract is fully

justified by the physical conditions encountered in the water development. Moreover, the water delivered to the water company will be used in any event in the immediate vicinity of Santa Barbara or for the beautifying and improvement of the town.

A section of the proposed new tunnel is shown in figs. 16 and 17 (pp. 91, 92), the timbered section being used only where necessary and the rock section being the prevailing type for the tunnel.

CONTRACT FOR CONSTRUCTION.

The work of driving the tunnel was divided into two parts, a southern portion of the tunnel to be 11,000 feet long and constructed from the south portal, and a northern portion to be 8,560 feet long and constructed from the north portal. Bids were called for and received, and the contracts awarded to F. J. Smith and E. J. Hunt, of Santa Barbara, for the south part, and to Robert Beyrle, of Los Angeles, for the north part. The prices were as follows:

Successful bids for new Santa Barbara tunnel.

	South division.	North division.
Per cubic yard of excavation	$8.00	$9.00
Overhaul per cubic yard per 100 feet (free haul being 500 feet)	.02	.01½
Timbers in place (per M feet, B. M.)	35.00	45.00

The total cost of the southern portion of the tunnel under the contract will be $109,125, and for the northern portion $90,267, a total of $199,392 for the entire tunnel. The estimate of the author, as consulting engineer for the work, was 19,560 feet of tunnel at $10 a foot, $195,600, plus 10 per cent for contingencies, or a total of $215,160. An additional allowance was made of 5 per cent for engineering expenses.

The yardage excavated in the tunnel is to be limited by the quantity shown on the section. After the completion of the work the contractor is required to leave his track in the tunnel for the purpose of hauling cement through it for the construction of the dam on Santa Ynez River, thus avoiding a wagon haul over the high mountains. The contracts were let in February, 1904.

VENTURA RIVER.

From an examination of the topographic maps of the Geological Survey, which have been recently prepared and which are of inestimable value in a general consideration of this subject, it was found that it would be possible by a gravity line to divert the headwaters of Ventura River from a point near the junction of the main and

north forks of Matilija Creek by gravity through Casitas Pass to Santa Barbara. A reconnaissance was made of this country, and a number of water measurements were made throughout the length of Ventura River. A month of minimum flow was selected as the proper time at which to make these determinations, as the minimum is the controlling condition in all questions involving water supply. There was a rainfall at Santa Barbara for the seasons of 1901–1902 of 14.06 inches. The stream flow during this season, however, was below normal.

TABLE 9.—*Flow measurements on Ventura River and tributaries.*

1902.	Locality.	Inches.
Sept. 25	At Matilija, above North Fork	99
25	North Fork at mouth	21
	Total, all diverted	120
25	River bed dry from Matilija School to near Coyote Creek	.....
25	Below Coyote Creek and below Domestic diversion	14
25	Head Domestic system's lower ditch	185
25	Head Domestic system's upper ditch	62
	Total Ventura River below and near Coyote Creek	261
26	Head of power ditch, below Domestic diversions	75
26	River bed above and near power house	8
	Total	83
26	Domestic ditch above and near reservoir	222

WATER AVAILABLE.

It will be noted that all of the water of Matilija Creek at the point from which a gravity line could be started to Santa Barbara is diverted and now in use, and consequently there was on that date no supply available for Santa Barbara at this point. In addition to this, the intervening topography is rugged and the distance would be very great, rendering it impracticable from a commercial standpoint to obtain a supply from this source.

It will also be noted that there were 75 inches of water diverted into the power ditch of the Ventura waterworks, which runs from a point approximately 4 miles north of Ventura to a point approximately 1½ miles north of this city, and that there were 8 inches of water above the point where this power ditch would discharge into the river, making a total of 83 inches in the lower portion of the river that was not diverted for domestic uses. During the daytime, at the time of the inspection, all this 75 inches of water was being used for irrigation, leaving but 8 inches of water in Ventura River

available for surface diversion. Information, however, was given that a portion of the water diverted through the domestic conduits during the daytime is accumulated in a certain domestic reservoir, and that at nighttime, from 11 p. m. until 6 a. m., a discharge of 280 miner's inches from this reservoir ordinarily takes place through the power house for the purpose of developing power and is wasted into the river. This is equivalent to a continuous flow of 82 miner's inches. This water wasted into the sea, taken in connection with the 8 inches flowing in the stream bed above the power house, makes a total of 90 miner's inches of water, which at this time, admitted to be one of drought, might be considered as wasted water and available for sale or disposal by the Ventura Water, Light, and Power Company. In addition to this, it is stated that the 75 inches of water diverted through the power ditch is not permanently sold for irrigation purposes, but is used by irrigators by sufferance on the part of the water company, and that the Ventura Water, Light, and Power Company could sell it to the city of Santa Barbara if it so desired. There thus might be made available from the lower portion of Ventura River a low-water supply of 165 miner's inches (2,145,000 gallons per day), provided all the above assumptions are correct.

The statement was made that there is practically a continuous use of the 30 inches of water from the power ditch during the daytime for irrigation, which might reduce these figures to 135 miner's inches (1,750,000 gallons daily). This is an unusually large amount of water to be available for disposal along this coast, and it was considered to be sufficient to justify a further investigation to determine the cost of its delivery to Santa Barbara.

The elevation at which this water could be obtained is practically 50 feet above sea level, and it would, therefore, have to be pumped to Santa Barbara through a long force main, laid possibly on the railroad right of way, for an aggregate distance of 26.2 miles. There is quite favorable opportunity of obtaining cheap fuel along this line, and a pumping station might be erected at the intake and a sufficient head generated to force the water through the pipe line, delivering it to the city of Santa Barbara at the foot of State street without pressure, in order to avoid the expense of a long pipe line designed to withstand high heads. At this point it would be picked up by a second pumping plant and forced to the high levels of the city. No legal examination of title was made as to the ownership of this water.

COST OF PIPING AND PUMPING.

It may be assumed, therefore, for the sake of estimating, that there is available from the lower Ventura River a supply of water

sufficient to furnish 1,500,000 gallons daily, adequate for 10,000 people using 150 gallons per capita each day. This is equal to 2.32 cubic feet per second, or 116 miner's inches of water. This water would have to be purchased from the Ventura Water, Light, and Power Company, from which no figure has as yet been obtained as to the price for which it would be sold. It is believed that the parties owning this water would be willing to contract for its delivery. If $300 per miner's inch were paid for this water, it would cost the city of Santa Barbara $34,800 at Ventura. An 18-inch continuous wooden stave pipe laid from the Ventura River to the foot of State street would be 138,300 feet in length, or 26.2 miles. The friction head to be overcome by water passing through this length of pipe, when carrying 1,500,000 gallons daily, would be 48.4 feet. It is believed that the average friction and hydraulic head on the pipe would be 50 feet. The pipe would be laid either on country roads or possibly along the railroad right of way. At certain projecting and precipitous cliffs the pipe would have to be run through tunnels. The conduit would be what is technically known as a continuous wooden stave pipe with steel bands, a form of construction which is satisfactory. It would be of a more permanent character than riveted pipe, but not of so enduring a nature as cast-iron pipe. Cast-iron pipe, however, because of its present high cost ($45 a ton delivered at Pacific coast terminals), would be entirely out of the question. The water would be delivered without pressure at the foot of State street, in order to avoid excessive cost due to necessarily stronger pipe required in case a high head was put on it to directly connect with the mains of the city for local distribution. From this point it would have to be lifted to domestic reservoirs. The following table is an estimate on the cost of laying such a pipe line:

TABLE 10.—*Estimated cost of Santa Barbara-Ventura pipe line.*

Section.	Length.	Class of excavation.	Cost.	Cost of excavation.	Cost of backfill.	Total cost of trenching.	Cost of pipe.	Total cost.
	Lin. ft.		*Lin. ft.*					
1	7,920	Trench	$0.15274	$1,209.70	$302.42	$1,512.12	$9,504.00	$11,016.12
2	6,864	do.	.191	1,311.02	327.75	1,638.77	8,236.80	9,875.57
3	2,640	do.	.15274	403.23	100.81	504.04	3,168.00	3,672.04
4	1,584	do.	.09546	151.21	37.80	189.01	1,900.80	2,089.81
5	1,320	Tunnel	5.00	6,600.00	.....	6,600.00	1,584.00	8,184.00
6	27,984	Trench	.09546	2,671 35	667.84	3,339.19	33,580.80	36,919.99
7	6,072	Tunnel	5.00	30,360.00	.....	30,360.00	7,286.40	37,646.40
8	7,392	Trench	.09546	705.64	176.41	882.05	8,870.40	9,752.45
9	5,280	Tunnel	5.00	26,400.00	.....	26,400.00	6,336.00	32,736.00
10	9,500	Trench	.17183	1,632.38	408.10	2,040.48	11,400.00	13,440.48
11	61,776	do.	.09546	5,897.14	1,474.28	7,371.42	74,131.20	81,502.62
Total	138,332	.....	.....	77,341.67	3,495.41	80,837.08	165,998.40	246,835.48

A portion of the line would be in ground that is quite alkaline. The wooden part of the pipe would not be attacked by the alkali, but the iron rods would be. If we assume a length of life for the pipe of twenty years, and that a sinking fund at 4 per cent interest would necessarily have to be provided to renew it at the end of that time, $8,287.54 would have to be set aside annually to meet the charge. At 4 per cent interest this would capitalize at $207,188, which should properly be added to the first cost of the pipe, giving $454,023 as the real cost of the pipe line to the city. This computation is given in order to compare the real cost of this pipe line with other permanent construction mentioned later.

It would be necessary to install two pumping plants, one at Ventura to force this water through the pipe line against the friction head, and the other to lift the water from the foot of State street to an assumed level of 300 feet to a domestic reservoir. The cost of the first plant would be $9,649, and of the second plant $13,970, or a total of $23,619. If a life of twenty years is assumed for pumping plants also, and provision is made for their renewal by a sinking fund as before, bearing 4 per cent interest, there would have to be set aside each year for this purpose $792.49, which is interest at 4 per cent on $19,802, making a total cost to the city of pumping plants of $43,421.

These pumping plants would be improved and modern triple-expansion condensing steam plants. The first plant would consume 5.5 barrels of crude oil daily, and the second 14.5 barrels of oil daily, or a total of 20 barrels of oil daily to deliver 1½ million gallons daily. This oil at $1 a barrel, which would be a fair price for a long period of use, would represent a daily charge of $20, and an annual charge of $7,300. Attendance of engineers and assistants would probably amount to $5,000 annually; so the oil and attendance together would be $12,300, which, capitalized at 4 per cent, represents $307,500.

To summarize we now have:

Summary of cost of Santa Barbara-Ventura pipe line.

	First cost.	First cost and maintenance.
1,500,000 gallons of water daily	$34,800	$34,800
Pipe line	246,835	454,023
Two pumping plants	23,619	43,421
Fuel and attendance		307,500
Total	305,254	839,744

This figure of first cost and maintenance would represent the real expense to the city of building and maintaining such a plant perpetually,

and on this basis can be properly compared with permanent construction, such as masonry.

This plant would practically be incapable of being increased in capacity without rebuilding the entire system, and no estimates have been included for rights of way.

SANTA YNEZ RIVER.

The county of Santa Barbara, by petition of its board of supervisors, and the city, through its trustees, requested the United States Geological Survey to make topographic surveys and hydrographic investigations in Santa Barbara County to assist in the solution of the difficult water problems which confront this beautiful coast district, often called the American Riviera. As it is the policy of the Geological Survey to carry on its work where the results will be of greatest value, it acceded to this request and has extended its topographic surveys over the greater portion of the county. Pl. I is made up from the results of these surveys. Hydraulic investigations have also been begun, three reservoirs surveyed, several tunnel lines triangulated, and three gaging stations established. It is intended to extend these investigations during the coming season so as to cover the entire drainage basin of Santa Ynez River. To a limited extent the city of Santa Barbara has cooperated financially in the hydraulic work.

Santa Ynez River rises in the mountains of Santa Barbara and Ventura counties, and flows westerly with a flat grade to the Pacific Ocean, having a length of approximately 75 miles. The Santa Ynez Range of mountains, varying in elevation from 3,000 to 4,000 feet, forms the southern boundary of this drainage basin. The northern divide ranges from 4,500 to 5,500 feet, culminating in Mount Pinos, the elevation of which is 8,826 feet. The mean elevation of the basin above the mouth of Mono Creek is 3,500 feet above sea level.

RAINFALL.

The mean rainfall at Santa Barbara is 16.78 inches; at Nordhoff, in Ventura County, at an elevation of 1,200 feet, it is about 18 inches; at Mutau Flat, on the headwaters of Piru Creek, and on the eastern slope of the range, at an elevation of 4,850 feet, it is 19 inches; at Snedden's ranch, on the north fork of the headwaters of the Piru, on the eastern slope of the mountains, at an elevation of 4,900 feet, it is 15 inches; at Cuddy's ranch, at an elevation of 5,000 feet, in Kern County, near the head of Tejon Creek, it is 20 inches, and at Old Fort Tejon, at an elevation of 3,245 feet, it is 18 inches. These records, except those of Santa Barbara, which were begun in 1867, are of rather short duration and fragmentary. The mean rainfall given for each mountain station is determined by finding the ratio of precipitation at Santa

Barbara for the years during which rainfall was observed at the high point in question, and the mean of the 37-year record at Santa Barbara, and applying that ratio to the observed rainfall at the mountain station. There are no known observations of rainfall in the upper portion of the Santa Ynez.

It is well known by the people living along the Pacific coast that the rainfall increases as the slope of the mountain ranges exposed to the sea breezes is ascended. Usually this increase amounts to six-tenths of an inch of rain for each 100 feet rise in elevation, which increase is to be added to the observed precipitation at the base of the range. On the eastern slope of the mountain ranges, on the side away from the ocean, this estimate does not at all hold, there being an actual diminution of rainfall after passing a crest. Consequently it is to be expected that such stations as Mutau Flat and Snedden's ranch, situated easterly from the main crest of the Coast Range, will have less precipitation than occurs on the exposed westerly side of the range. The Santa Ynez Range undoubtedly abstracts a portion of the moisture of the clouds that are passing inland over the drainage basin of Santa Ynez River, but the precipitation must again increase on the westerly sides of the high Coast Range on the northerly and easterly portions of the drainage basin, where the mountains rise from 2,000 to 3,000 feet higher than the summits of the Santa Ynez Mountains.

Mr. Purslow says that the rainfall in the basin of the Santa Ynez above the reservoir sites which he examined is 30 inches, and Mr. Wright states that in his judgment it is over 20 inches. Mr. Marsden Manson, civil engineer of the California Water and Forest Association, prepared a rainfall map, showing precipitation throughout the State, on which he estimates the rainfall in this district as between 20 and 30 inches. Mr. William Hammond Hall, when State engineer of California, also prepared a rainfall map, showing the precipitation for this district to be between 20 and 30 inches. Lieutenant Glassford, of the United States Signal Service, in 1891 officially estimated the rainfall on the headwaters of the Santa Ynez at from 20 to 25 inches.

After a careful examination of the drainage basin, of the vegetation covering it, of available rainfall records, and from a general knowledge of the precipitation throughout this portion of the State, the writer believes that the average rainfall in this basin is about 22 inches. However, in order to be within safe limits in making the estimates of available water supply, the same rainfall is used for computing the run-off of the Santa Ynez basin as has been observed at Santa Barbara.

RUN-OFF.

The question of determining the relation of what is called run-off (or the amount of water the streams discharge) to rainfall is one of considerable difficulty and uncertainty. It is dependent upon the character of the rains, whether gentle showers or violent storms (the latter yielding the greater run-off), and also upon the steepness of the slopes and the size of the watershed. Other things being equal, the small watershed has the higher percentage of run-off. A one or two years' record does not establish a final ratio.

The forest cover of the drainage basin also greatly affects the run-off. If it is a denuded area the floods are more violent and shorter in duration and the summer stream is much lower. If the drainage basin has a proper forest or brush cover the stream is more uniform in flow and carries less silt. The general porosity of the soil and rock also affects the character of the run-off.

A number of efforts have been made to establish this ratio of rainfall to run-off. The diagram presented herewith as fig. 1 (p. 15) shows by curved lines on a horizontal scale the amount of rainfall in inches of depth, and on the vertical scale the total corresponding volume of water discharged in acre-feet, an acre-foot of water being the amount that will cover 1 acre 1 foot deep, or 43,560 cubic feet. The curve which is used in this report is one that has been determined as the result of a large number of measurements in California made by the United States Geological Survey. It will be noted that it indicates less run-off than the others.

The Salt Springs Valley reservoir is in Calaveras County, Cal., in the foothills. The Newell curve for "mountainous areas" is a general determination, by Mr. F. H. Newell, hydrographer of the Geological Survey, for the high mountain areas of the western portions of the United States. The Arrowhead reservoir is in San Bernardino County, Cal. The Newell curve for "undulating areas" is the relation determined by Mr. Newell for hill countries. The general curve for large watersheds for California is the one used in this report as the result of California observations made largely during the drought period through which we have passed. It will be noted that there is no run-off indicated until after the rainfall exceeds 10 inches. All of these curves are much more unfavorable to large run-off than has customarily been accepted for eastern streams.

TABLE 11.—*Record of precipitation at Santa Barbara, Cal.*

[Latitude, 34° 25′; longitude, 119° 40′. Elevation, 100 feet. Authority, War Department and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1867-68	0.00	0.00	2.31	12.67	3.97	2.00	1.08	2.44	0.72	0.00	0.00	0.00	25.19
1868-69	.00	.00	1.25	4.26	3.26	2.12	4.22	.46	.20	.00	.00	.00	15.77
1869-70	.00	.30	.65	.57	.25	5.87	.83	.99	.74	.07	.00	.00	10.27
1870-71	.00	1.04	.27	1.41	.86	2.92	.02	2.02	.37	.00	.00	.00	8.91
1871-72	.00	.09	1.83	6.56	2.53	1.81	.18	1.80	.00	.14	.00	.02	14.96
1872-73	.05	.00	.00	4.34	.58	5.48	.05	.00	.00	.00	.00	.00	10.50
1873-74	.00	.00	.27	5.26	4.54	3.17	.78	.28	.14	.00	.00	.00	14.44
1874-75	.00	1.91	1.30	.00	14.84	.18	.38	.10	.00	.00	.00	.00	18.71
1875-76	.00	.00	6.53	.31	7.56	5.67	2.73	.27	.00	.00	.00	.00	23.07
1876-77	.00	.32	.00	.00	2.72	.00	.82	.18	.45	.00	.00	.00	4.49
1877-78	.00	.00	1.32	3.12	7.17	11.73	2.47	3.34	.29	.07	.00	.00	29.51
1878-79	.00	.32	.00	5.16	5.24	.71	.34	1.60	.21	.00	.00	.00	13.58
1879-80	.00	.41	1.62	4.57	1.30	10.86	1.15	5.73	.00	.00	.00	.00	25.64
1880-81	.00	.25	.28	9.73	2.83	.30	1.25	.59	.00	.00	.00	.00	15.23
1881-82	.44	1.47	.33	.95	1.13	2.38	5.74	1.63	.00	.20	.00	.00	14.27
1882-83	.00	.37	.77	.10	2.18	2.92	3.64	.29	2.79	.35	.00	.00	13.41
1883-84	.00	1.32	.00	2.76	6.33	9.68	9.77	2.60	.39	1.62	.00	.00	34.47
1884-85	.00	1.02	.79	6.62	1.23	.07	.35	3.00	.00	.00	.00	.00	13.08
1885-86	.00	.19	9.84	2.47	5.12	1.19	2.03	3.40	.00	.00	.00	.00	24.24
1886-87	.00	.39	.87	.86	.31	8.64	.13	1.43	.33	.03	.00	.00	12.99
1887-88	.38	.31	1.10	4.43	10.15	1.30	3.86	.16	.02	T.	T.	T.	21.71
1888-89	.03	.07	5.62	5.59	.29	1.29	7.21	.49	.76	.13	.00	.00	21.58
1889-90	.00	8.65	3.21	10.64	5.32	2.96	1.10	.31	.18	.00	.00	.00	32.37
1890-91	1.50	.00	.48	3.53	.50	8.82	1.65	1.90	.00	.00	.00	.00	18.38
1891-92	.18	.00	.00	2.26	1.04	2.48	3.36	.34	.62	.00	.00	.00	10.28
1892-93	.00	.42	3.70	7.31	4.52	3.55	7.53	.38	.00	.00	.00	.00	27.41
1893-94	.00	.62	T.	3.50	.65	.50	.22	.35	.86	.00	.15	.00	6.85
1894-95	1.36	.78	.11	4.16	6.25	.67	1.99	.46	.02	.05	T.	.00	15.85
1895-96	.00	.55	.77	.93	6.84	.00	2.37	1.78	.08	.05	.40	.00	13.77
1896-97	.00	.92	3.51	2.92	4.35	3.65	2.73	.02	.00	.00	.00	.00	18.10
1897-98	.00	1.44	.00	.00	.63	1.39	.28	T.	1.25	.00	T.	.00	4.99
1898-99	3.17	.14	.00	.36	4.48	.00	2.78	.64	.00	.78	.00	.00	12.35
1899-1900	.00	2.06	1.97	2.35	2.32	.05	1.58	.42	1.90	.01	.02	T.	12.68
1900-1901	.04	.15	3.99	.02	4.86	3.65	.16	2.07	.34	.10	.06	.09	15.53
1901-2	.36	2.42	1.16	T.	1.36	4.40	2.89	1.40	.07	.00	.00	.00	14.06
1902-3	.00	1.48	4.01	2.24	2.06	1.63	6.12	2.91	.00	.00	.00	.00	20.45
1903-4	T.	T.	.05	T.	.46	4.69	4.40	1.89	.09	.00	.00	.10	11.68
37-year mean													16.78

As has been previously stated, the rainfall for the drainage basin of the Santa Ynez above the Mono, and for Mono Creek, is taken in the computations as 16.78 inches as an average, which is the rainfall observed for thirty-seven years at Santa Barbara.

The drainage area above the various reservoir sites was carefully determined from the topographic surveys of the Geological Survey which have been recently made. The area above the Juncal reservoir site is 13.4 square miles; above the Mono reservoir site, 119 square miles; above the Main River reservoir site, on the Santa Ynez just below the mouth of Blue Canyon, 71 square miles; above the Gibraltar reservoir site on the main river, 207 square miles.

The exposure of the drainage basin of the Santa Ynez proper is more favorable for a large amount of run-off than that of the Mono. The rainfall usually increases as the mountains rise in elevation, but the heaviest precipitation is generally just beyond the crest of the range of hills; consequently we would expect an unusually large precipitation just beyond the summit of the Santa Ynez Range north of Santa Barbara. Moreover, this exposure being a northern one, there is less loss by evaporation from the soil. This rainfall is strikingly indicated by the brush cover on the Santa Ynez Mountains as compared with the cover in the drainage basin of the Mono.

As an illustration, it may be mentioned that during the season of 1902–3 the Mono drainage basin discharged 8,934 acre-feet of water from 119 square miles; the Santa Ynez above the Mono discharged 9,898 acre-feet from 71 square miles, and the basin above the Gibraltar dam site discharged 21,202[a] acre-feet from 207 square miles.

By applying the diagram (fig. 1) showing the relation of rainfall to run-off to the drainage areas of each of the sites, the probable volume of water available at each in each year has been obtained and is given in the last three columns of table 12. It will be noted that there is a very great fluctuation in the volume discharged in various years. For instance, in 1875–76 there were probably 35,190 acre-feet of water discharged through the Gibraltar reservoir site; in the following year there were no flood discharges whatever; while in the year 1877–78 there were probably 66,240 acre-feet. This is a strong argument in favor of building reservoirs of sufficient capacity to hold over from years of abundance to years of deficiency. It would not be possible to catch and retain all the water in all of the years, as there is a limit to the height of dam that should be built to be commercially profitable.

In consulting a table of estimated discharge of stream flow for any given section, it must be borne in mind that the figures are purely hypothetical, exact determination being impossible, for numerous reasons. The character of the run-off is dependent upon the character of each particular rain storm, whether it is a gentle shower or violent downpour. Again, one storm quickly following another will produce a greater stream discharge, because there is less opportunity of absorption of the rain by the ground. The character of the exposure, forest cover, etc., all enter into the considerations, rendering the question one of great intricacy. The table given is based upon general results obtained in southern California and must be considered merely as an estimate made from the most reliable data in hand. In order to obtain intelligent results along these lines, it is exceedingly important for the city of Santa Barbara to maintain gagings on Santa Ynez River continuously, particularly during the construction of the tunnel prior to the building of the dam at Gibraltar.

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[a] Estimated.

TABLE 12.—*Hypothetical run-off for Santa Ynez reservoir sites on basis of observed Santa Barbara rainfall and run-off diagram.*

Year.	Rainfall of Santa Barbara and Santa Ynez.	Run-off per square mile in acre-feet.	Total run-off in acre-feet.			
			Juncal (drainage area, 13 square miles).	Mono (drainage area, 119 square miles).	Main river (drainage area, 71 square miles).	Gibraltar (drainage area, 207 square miles).
1867–68	25.19	210	2,730	24,990	14,910	43,470
1868–69	15.77	60	780	7,140	4,260	12,420
1869–70	10.27	.....	.....	.....	.....	.....
1870–71	8.91	.....	.....	.....	.....	.....
1871–72	14.96	50	650	5,950	3,550	10,350
1872–73	10.50	.....	.....	.....	.....	.....
1873–74	14.44	40	520	4,760	2,840	8,280
1874–75	18.71	105	1,365	12,495	7,455	21,735
1875–76	23.07	170	2,210	20,230	12,070	35,190
1876–77	4.49	.....	.....	.....	.....	.....
1877–78	29.51	320	4,160	38,080	22,720	66,240
1878–79	13.58	40	520	4,760	2,840	8,280
1879–80	25.64	230	2,990	27,370	16,330	47,610
1880–81	15.25	50	650	5,950	3,550	10,350
1881–82	14.27	40	520	4,760	2,840	8,280
1882–83	13.41	30	390	3,570	2,130	6,210
1883–84	34.47	430	5,590	51,170	30,530	89,010
1884–85	13.08	30	390	3,570	2,130	6,210
1885–86	24.24	190	2,470	22,610	13,490	39,330
1886–87	12.99	30	390	3,570	2,130	6,210
1887–88	21.71	150	1,950	17,850	10,650	31,050
1888–89	21.58	150	1,950	17,850	10,650	31,050
1889–90	32.37	370	4,810	44,030	26,270	76,590
1890–91	18.38	90	1,170	10,710	6,390	18,630
1891–92	10.28	.....	.....	.....	.....	.....
1892–93	27.41	255	3,315	30,345	18,105	52,785
1893–94	6.85	.....	.....	.....	.....	.....
1894–95	15.83	60	780	7,140	4,260	12,420
1895–96	13.77	40	520	4,760	2,840	8,280
1896–97	18.10	90	1,170	10,710	6,390	18,630
1897–98	4.99	.....	.....	.....	.....	.....
1898–99	12.35	20	260	2,380	1,420	4,140
1899–1900	12.68	30	390	3,570	2,130	6,210
1900–1901	15.53	60	780	7,140	4,260	12,420
1901–2	14.06	40	520	4,760	2,840	8,280
1902–3	20.45	120	1,560	[a] 14,280	[b] 8,520	24,840
1903–4	11.68	15	195	1,785	1,065	3,105

[a] Measured flow, 8,934 acre-feet. [b] Measured flow, 9,898 acre-feet.

TABLE 13.—*Measured run-off of Santa Ynez River and Mono Creek for 1902–3.*

Month.	Total run-off in acre-feet.	
	Mono at dam site (drainage area, 119 square miles).	Main river above Mono (drainage area, 71 square miles).
1902.		
July	0	0
August	0	0
September	0	0
October	0	0
November	173	280
December	12	111
1903.		
January	676	1,193
February	389	755
March	1,845	1,230
April	4,820	4,998
May	799	1,045
June	220	286
	8,934	9,898
Estimate for 1902–3	14,280	8,520
Run-off for 1902–3, in acre-feet per square mile	75.1	139.4
1903.		
July	21	68
August	10	31
September	7	18
October	3	9
November	2	[a] 12
December	3	[a] 14
	46	152

[a] Estimated.

Run-off at Gibraltar, in acre-feet, for 1902–3.

[Estimated.]

Mono at dam site	8,934
Santa Ynez above Mono	9,898
17 square miles below Mono, estimated (17 × 139.4)	2,370
Total for Gibraltar	21,202

Total run-off, in acre-feet, of main river at Gibraltar dam site.

[Drainage area, 207 square miles.]

1903.[a]		1904.	
July	0	July	2
August	0	August	0
September	0	September	11,484
October	0	October	535
November	0	November	381
December	17	December	430
1904.		**1905.**	
January (7-31)	45	January	4,538
February	690	February	39,753
March	1,857		
April	1,125		
May	418		
June	42		
Total for season	4,194		

It is suggested that a reservoir should be so constructed as to supply at least 150 gallons per capita daily for a population of 10,000, the use and evaporation in this case amounting to about 2,100 acre-feet yearly. At the Mono reservoir site a dam 85 feet high, holding water to a maximum depth at the dam of 75 feet, would give this continuous supply for nineteen months. At the Gibraltar reservoir site a dam 100 feet high would impound a two years' supply, and a dam 155 feet high would have a capacity of 15,793 acre-feet. These figures as to flow of the streams and capacities of reservoirs indicate the adequacy of a system based upon these physical conditions. The records of stream flow should be continuously maintained to assist in the determination of the requisite height of dam.

QUALITY OF WATER.

The quality of the water in the neighborhood of Santa Barbara has been made the subject of long study by Prof. James A. Dodge, of Santa Barbara. Herewith are given certain analyses made by him of the water of creeks in this vicinity. Although these are not absolutely complete, inasmuch as small quantities of minerals present are not stated, they were made with care. Other complete analyses that were made subsequently show no material difference from the results given. The analysis of the water of the city tunnel as supplied to consumers in Santa Barbara was made at the request of Doctor Cassal, health officer in 1899. The amount of mineral substances in solution in the tunnel water does not materially differ from that shown by the analysis made of Mission Creek waters in 1894. Other analyses made by Professor Dodge at various times, of waters from the wells

[a] Estimated.

in the city, show them to be, generally speaking, very similar to the creek water. Professor Dodge concludes that the ordinary water in use for domestic purposes from the strip of country between Santa Ynez Mountains and the ocean is practically uniform in quality. There are, however, exceptional waters in this vicinity differing decidedly from those above referred to, one of these being the Veronica water, and another the water from the Hot Springs.

ANALYSES OF SAMPLES.

Certain analyses were made of the water from Mono Creek by Prof. Laird J. Stabler, chemist for the University of Southern California and also for the Southern California Medical College, one (No. 5) being of the low summer flow, consisting of merely a few miner's inches seeping through the sands and gravels and naturally containing an abnormally large amount of mineral matter. Another (No. 7) was of the water from the first floods from the drainage basin, which, as is customary after a long drought, carried some of the accumulated salts deposited along the margins of the stream by summer evaporation, and also a large amount of pulverized sediment trampled by stock during the preceding summer and readily picked up and carried away by the first dash of water over the ground. These analyses of the low-water stage at the end of a dry season and the first flood water are the most unfavorable that could be made. The analyses of the later floods, made as the season advanced, give smaller amounts both of silt and of mineral matter, as shown in analyses No. 9 and No. 12.

Analysis No. 1, water of Mission Creek.

[Analyst, James A. Dodge; date of analysis, June, 1894.]

	Grains per U. S. gallon.
Sodium chloride	1.28
Sodium sulphate	6.95
Calcium sulphate	7.45
Calcium carbonate	6.02
Magnesium carbonate	4.21
Potassium carbonate	Trace.
Alumina and iron salts	Trace.
Silica	Trace.
Total	25.91

Reaction of residue left by evaporation in a platinum dish, slightly alkaline.

Analysis No. 2, water of Cold Spring Creek.

[Analyst, James A. Dodge; date of analysis, June, 1894.]

	Grains per U. S. gallon.
Sodium chloride	1.05
Sodium sulphate	5.96
Calcium sulphate	10.63

	Grains per U. S. gallon.
Calcium carbonate	6.25
Magnesium carbonate	6.54
Potassium carbonate	Trace.
Alumina and iron salts	Trace.
Silica	Trace.
Total	30.43

Reaction of residue left by evaporation in a platinum dish, slightly alkaline.

Analysis No. 3, water from the Santa Barbara city water tunnel.

[Analyst, James A. Dodge; analysis made in November, 1899, for Doctor Cassal, health officer.]

	Grains per U. S. gallon.
Sodium chloride	0.537
Sodium sulphate	8.392
Magnesium sulphate	3.118
Magnesium carbonate	1.769
Calcium carbonate	14.097
Iron carbonate	.122
Potassium carbonate	.379
Lithium salts	Trace.
Silica	Trace.
Nitrates	Trace.
Organic carbonaceous matter	Trace.
Total	28.414

Analysis No. 4, water from Santa Ynez River at gaging station one-half mile above mouth of Mono Creek.

[Collected by S. G. Bennett, January 4, 1903; analyst, Laird J. Stabler. Clear water; low stage before winter floods.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	2.72	4.68
Sodium sulphate	29.82	51.19
Sodium carbonate	16.57	28.41
Total solids	42.91	73.60

Analysis No. 5, water from Mono Creek at gaging station near mouth.

[Collected by S. G. Bennett, January 4, 1903; analyst, Laird J. Stabler. Clear water, low stage.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	5.94	10.20
Sodium sulphate	58.28	99.94
Sodium carbonate	17.94	30.74
Total mineral matter	81.64	140.00

Analysis No. 6, water from Santa Ynez River above mouth of Mono Creek.

[Collected by W. B. Clapp, November, 1902; analyst, Laird J. Stabler. First flood.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	2.50	3.5
Sodium sulphate	38.25	65.6
Sodium carbonate	10.13	17.38
Total solids in suspension	1,749.50	2,640.00
Total solids in solution	67.64	116.00

Solid matter deposited in 30 hours, 7.3 per cent by volume; solid matter deposited in 3 days, 7.3 per cent by volume.

Analysis No. 7, water from Mono Creek near dam site.

[Collected by W. B. Clapp, November, 1902; analyst, Laird J. Stabler. First flood.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	2.3	3.94
Sodium sulphate	33.11	56.80
Sodium carbonate	9.51	16.32
Total solids in suspension	342.80	931.00
Total solids in solution	57.15	98.00

Solid matter deposited in 30 hours, 4 per cent by volume; solid matter deposited in 3 days, 4.1 per cent by volume.

Analysis No. 7, water from Mono Creek.

[Collected January 24, 1903, at low stage; analyst, James A. Dodge.]

	Grains per gallon.
Suspended siliceous matter, separated by filtration	1.46
Sodium chloride	5.49
Sodium carbonate	3.73
Sodium sulphate	13.14
Magnesium sulphate	22.43
Calcium sulphate	10.34
Calcium carbonate	16.99
Aluminum sulphate	1.17
Iron salts	Trace.
Potassium salts	Trace.
Organic matter	Trace.
Total dissolved substances	73.29

The following analyses of waters from Mono Creek and Santa Ynez River were taken from the low stage of the stream subsequent

to the first flood, but it is believed that they still contained abnormally high quantities of solids in solution:

Analysis No. 8, water from Santa Ynez River at cable station.

[Collected by H. Rankin, January 29, 1903; analyst, Laird J. Stabler. Low stage.]

	Grains per gallon.	Parts per 100,000.
Chlorides as sodium chloride	2.04	3.5
Carbonates as sodium carbonate	14.45	24.8
Sulphates as sodium sulphate	18.49	31.72
Total solids in solution	34.99	60.00
Total solids in suspension (0.02 per cent)	11.66	20.00

Analysis No. 9, water from Mono Creek at cable station.

[Collected by H. Rankin, January 29, 1903; analyst, L. J. Stabler.]

	Grains per gallon	Parts per 100,000.
Chlorides as sodium chloride	3.67	6.3
Carbonates as sodium carbonate	10.99	18.86
Sulphates as sodium sulphate	37.00	63.44
Total solids in suspension (0.02 per cent)	13.99	24.00
Total solids in solution	56.20	97.2

Analysis No. 10, water from Santa Ynez River at cable station.

[Collected by H. Rankin, January 30, 1903; analyst, L. J. Stabler.]

	Grains per gallon.	Parts per 100,000.
Chlorides as sodium chloride	2.04	3.5
Carbonates as sodium carbonate	16.31	27.98
Sulphates as sodium sulphate	18.64	31.96
Solids in solution	44.51	69.2

Analysis No. 11, water from Mono Creek at cable station.

[Collected by H. Rankin, January 30, 1903; analyst, L. J. Stabler.]

	Grains per gallon.	Parts per 100,000.
Chlorides as sodium chloride	3.67	6.3
Carbonates as sodium carbonate	14.60	25.01
Sulphates as sodium sulphate	44.10	75.64
Solids in solution	65.42	112.0

Analysis No. 12, water from Mono Creek.

[Collected by H. Rankin, January 28, 1903; analyst, James A. Dodge. Flood water.]

	Grains per gallon.
Sodium chloride	0.99
Sodium carbonate	1.05
Sodium sulphate	7.59
Magnesium sulphate	3.52
Calcium sulphate	6.07
Calcium carbonate	7.83
Iron carbonate	.88
Potassium salts	Trace.
Organic matter	Trace.
Total	27.93

This water contained silt, suspended and subsided, consisting mainly of clay, but containing some fragments of vegetable matter, and amounting to 3½ per cent by weight of the total water. This silt subsided with moderate quickness and left the water clear in somewhat less than three days.

Analysis No. 13, water from Mono Creek.

[Collected by H. Rankin, February 26, 1903; discharge, 4.50 second-feet; analyst, L. J. Stabler.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	4.01	6.87
Sodium carbonate	2.00	3.43
Sodium sulphate	14.85	25.46
Potassium sulphate	1.02	1.72
Calcium sulphate	30.45	52.22
Calcium carbonate	3.82	6.56
Magnesium carbonate	8.42	14.43
Total	64.57	110.69

The mineral matter is rather excessive for domestic purposes. The alkali salts are not beyond the limit for irrigation, but amount present would be large for some soils. The water would form considerable hard scale in boilers. As this is a low-water sample, it shows more mineral salts than flood-water samples.

Analysis No. 14, water from Mono Creek.

[Collected by H. Rankin, February 26, 1903; discharge, 4.5 second-feet; analyst, James A. Dodge.]

	Grains per gallon.
Sodium chloride	3.97
Sodium carbonate	3.91
Sodium sulphate	13.84
Magnesium sulphate	21.55
Calcium sulphate	8.37
Calcium carbonate	22.02
Iron carbonate	Trace.
Aluminum sulphate	0.52
Potassium salts	Trace.
Silica	0.41
Total	74.59
Suspended matter	0.29

Analysis No. 15, from Santa Ynez River at Gibraltar.

[Collected by L. M. Hyde, May 2, 1904; discharge, 16.97 second-feet; analyst, James A. Dodge.]

1. General character of the water.

Clear, colorless, free from odor, of good taste; showing a slight sediment in the bottle, not sufficient for quantitative determination. Reaction slightly alkaline.

2. Organic matter.

A microscopic examination of the very small amount of matter separated by filtering, including the above-mentioned sediment, showed some plant fibers and parts of vegetable organisms; also a few infusoria in a state of activity. These are usually present in river and lake waters.

3. Chemical analysis of the mineral matter in solution.

	Parts per 100,000.	Grains per U. S. gallon.
Calcium carbonate	34.98	20.393
Calcium sulphate	4.03	2.350
Magnesium sulphate	25.78	15.030
Sodium sulphate	12.57	7.328
Sodium chloride	3.64	2.122
Potassium carbonate	1.05	0.612
Lithium salts	Trace.	Trace.
Iron salts	Trace.	Trace.
Nitrates	Trace.	Trace.
Silica	Trace.	Trace.
Total	82.05	47.835

The foregoing substances are to be understood as in the anhydrous state.

	Degrees.
Total hardness	37
Permanent hardness	20
Temporary hardness	17

The total and the permanent hardness were determined by the use of a standardized soap solution. The temporary hardness is found by subtracting the permanent from the total.

The U. S. gallon of 231 cubic inches is the basis of these results, not the imperial gallon, as formerly customary.

This analysis shows that the water is of good quality for domestic use and for irrigation. For table use, like the water of all streams in this vicinity, it would be improved by boiling and settling. This process removes a considerable part of the mineral matter and destroys infusoria and other living organisms. For use in steam boilers it would be advisable to submit this water to a softening treatment before taking it into the boilers.

DISCUSSION OF ANALYSES.

Up to January 28, 1903, this season was not productive of floods, the precipitation having been largely in the form of snow in the higher mountains, and the high water occurring later in the spring. For this reason all of the samples except Nos. 6, 7, and 12 were taken

when the stream was at low stage. The water that runs off the surface of the ground in floods will not contain as much mineral matter as that which seeps through the soil into the stream during its low stage. Samples Nos. 12 and 13 show this to be true. It is probable that over 80 per cent of the total annual discharge of the Mono will be in freshets. This being the case, we may expect the water that is stored in reservoirs to be more nearly like the flood-water than the low-water samples analyzed. If the low-water flow tends to deteriorate the whole impounded in the reservoir, it may be carried around the reservoir in a conduit.

The first flood that is flushed over the surface of a drainage basin after a drought will absorb more mineral matter than later floods will find. Thus sample No. 12 shows better water than No. 7. Sample No. 12, from the second flood water of the Mono, shows a water practically the same as that now being used by the city of Santa Barbara from Mission Creek and the city tunnel. The low-water samples contain a high per cent of mineral, but even they are pronounced harmless by Mr. Dodge. The water of the Santa Ynez above the Mono is better than the Mono water. The water stored at the Gibraltar site would be a blended water, grading between the two; and in view of the fact that this is the only source of supply open to the city for an adequate amount of water, it is believed that it should be accepted.

Prof. James A. Dodge, a chemist of marked and recognized ability, residing at Santa Barbara, who made a number of the foregoing analyses, gives the following statement about the quality of this supply:

On the supposition that the proposed reservoir on Mono Creek will be filled with the flood water of the creek, but that the water running in the creek during its low stages will also pass into the reservoir, the water as supplied to this city from that source will in its composition come between the samples analyzed by me and reported on the 16th and 21st of February [No. 12] and the 4th of March [No. 14], and might under certain conditions approximate to the first of these samples.

Considering, therefore, this low-water sample, I call attention to the fact that the principal mineral ingredients—that is, those present in greatest quantity—are the familiar calcium and magnesium salts of our hard waters. A person drinking a quart of this water would take into his stomach from 12 to 13 grains of these salts. He would at the same time take about 5 grains of sodium salts, equally common in our natural waters as used for domestic purposes, together with a very small amount of other harmless mineral substances.

In my opinion, these quantities of all these substances, taken in water, would not be sufficient to produce any deleterious or unpleasant effects upon a person in good health, properly supplied with food. Nor would the habitual use of the water bring about any bad consequences. In the case of some persons in delicate health, or of persons fasting, the same substances in the same quantity contained in the water would probably have the medicinal action of an aperient. This opinion is based on actual experience in the use of such water by myself and by others in the same company.

I will add that this water by being boiled would be caused to deposit a part of the calcium and magnesium salts, in the form of carbonates, and would thereby be improved. Furthermore, aside from the removal of a part of the mineral matter, all water taken from streams and lakes, in view of the possibility of its contamination by disease germs, needs boiling to make it perfectly safe for domestic use. After being boiled and decanted from the precipitated substances, the water, if placed in a suitable receptacle, will keep as long as may be desired and will be quite potable from first to last.

As regards the use of the Mono Creek water for cooking purposes, in my opinion the quantity of mineral substances introduced into the articles cooked with it would not be sufficient to produce any noticeable effects.

For washing this is a hard water. It would, with ordinary soaps, be somewhat more troublesome than the waters now supplied to the people of this city.

In the irrigation of trees, shrubs, and other plants, this water would not produce any injurious effects, unless applied in extraordinary quantity or on soil with little or no drainage.

It must be admitted that these waters are not of high grade for domestic use because of the large quantities of mineral matter in solution, but it is not believed that they will be injurious to health, nor will they be harmful to vegetation. The sulphate of sodium is not harmful, and the sulphate of lime tends to neutralize the carbonates. All stream waters contain more or less mineral matter. Chemically pure water is neither pleasant to drink nor healthful. The question of soils becoming alkaline from irrigation with salty water is largely dependent upon the slope and drainage that the soil itself has. In a hill country water containing unusual quantities of alkali may be used with impunity, while in a flat country a water of much better grade could not be applied in irrigation without producing bad effects. No organic impurities, which are most to be feared, will be found in these waters in dangerous quantities.

It should be stated that the samples Nos. 4 to 11, given Professor Stabler, were not large enough in volume to permit of complete analysis.

Mr. Thomas H. Means,[a] of the Bureau of Soils of the Department of Agriculture, makes the following comment upon the quality of the water as indicated by the foregoing analyses:

I have examined the analyses given in your report to the city water commissioners of Santa Barbara, Cal., with a view to determining whether these waters would be considered favorable for city use or not. I have considered the sources as free from contamination through animals and consequently have confined my attention to the mineral ingredients which the water carries.

As I understand the situation, the water which you propose to carry through the mountains by a tunnel is to be stored in a reservoir on Santa Ynez River and comes in something like equal parts from Santa Ynez River and Mono Creek. The analyses in your report are

[a] Mr. Means has since been appointed engineer of soils of the Reclamation Service.

from samples taken from both streams. The following table is a recapitulation of the analyses, showing only the total solids in 100,000 parts of water:

Comparison of analyses of Santa Ynez and Mono water.

Date.	Stage of Santa Ynez River.	Parts per 100,000.	Date.	Stage of Mono Creek.	Parts per 100,000.
1903.			1903.		
Jan. 4	Low stage before floods.	73.60	Jan. 4	Low stage before floods.	140.00
Nov.[a] —	First flood	116.00	Nov.[a] —	First flood	98.00
Jan. 29	Low stage	60.00	Jan. 29	Low stage	97.20
30	do	69.20	30	do.?	112.00
			28	Flood	48.30
			26	Low water	110.69
			26	do	129.00

[a] 1902.

All of these samples, with one exception, are collected at low stage of the stream, when the amount of soluble matter is usually highest, or at first flood after the dry season, when the accumulations of saline matter from the surface of the soil are swept into the stream. So these analyses probably represent the worst condition of the water. The only flood sample is that from the Mono Creek collected January 28, 1903, and its analysis shows considerably less than half the soluble matter found in the low-stage flow of the stream. I presume if flood samples were collected from the Santa Ynez a similar falling off in amount of soluble matter would be noted. The importance between this difference in low-water and flood stages is very great, especially where the floods can be stored and where it may be possible to divert the low-water flow and carry it around the reservoir.

The waters of Mono Creek seem to carry much more soluble matter than do those of the Santa Ynez. The average of the analyses given under the first four dates in the table shows Mono Creek to carry nearly 49 per cent more soluble matter than does Santa Ynez River. If the same ratio holds during the flood season the mixture of waters in the two streams should carry less than 40 parts per 100,000 parts of water, or a water, as will be shown later, which, according to the most rigid standards in eastern cities and in Europe, would be classed as "good" for domestic use. On the other hand, if the low-water discharge alone is considered the average of a mixture of the two waters would be about 114 parts per 100,000. Later I will show that according to accepted standards this amount of soluble matter is well within the limit of western American sanitary engineers.

The standard most generally accepted in eastern United States and Europe allows 50 parts per 100,000 parts of water. More than that quantity serves to condemn a water or class it as a water only "fair" for domestic use, while waters carrying less than 50 parts are classed generally as good. E. W. Hilgard, of the University of California, places the limit for domestic use at 40 grains per gallon (68.6 parts per 100,000). J. K. Haywood, chief of the water laboratory of the Bureau of Chemistry in the United States Department of Agriculture, in an article on Analysis of Waters and Interpretation of Results, published in the Department of Agriculture Yearbook for 1902, makes the following statement: "Some water analyzers would cast aside all doubt by declaring that waters containing above 686 parts per million (68.6 parts per 100,000) are to be condemned, but such is not the case, as there are many instances, especially in the West, of water containing 1,200 parts per million (120 parts per 100,000) and over being used without apparent evil results."

As a matter of precedent, I might say that there are a number of small western towns

using water carrying more than 100 parts soluble matter per 100,000 parts of water, and that the city of Phoenix, Ariz., supplies about 15,000 people with water carrying from 102 to 136 parts, without apparent inconvenience or harmful effect. Numerous domestic supplies for families have been observed by myself carrying from 400 to 500 parts per 100,000, all without evil effect and with no inconvenience except that the waters were unpalatable at first. The inhabitants of some parts of the Southwest have become so used to the saline waters that I have seen pure water salted at table to bring back the familiar taste.

I find it very difficult to draw any definite conclusions from the character of the salts in the water, for I am not familiar with the methods employed by the chemists in calculating these analyses. However, it seems that the most important constituents are salts of lime. These serve to make the water hard, will cause considerable losses in soap used, and will give trouble in boiler use by forming scale. I can not say how much of this hardness is "temporary" and how much "permanent." The two analyses, Nos. 13 and 14, are evidently made from duplicate samples by two chemists working independently. One of them, No. 13, would be classed as a hard water with nearly all the hardness permanent, or, in other words, it could not be removed by boiling. On the other hand, when we consider analysis No. 14, nearly one-half of the hardness is temporary, or could be removed by simply boiling and allowing the sediment to settle. If a new set of analyses were made I would suggest they be made by some accepted standard of water analyses and both "temporary" and "permanent" hardness be determined.

Of the other salts present only the sodium sulphate and magnesium sulphate are present in sufficient quantity to warrant consideration. Both these salts are laxative, but only the most delicate constitutions would be affected by the small amounts taken in this water. Newcomers to the locality might notice the effect of the water for a few days, but I am sure no evil effects can possibly come from the constant use of such water.

The small amounts of sodium carbonate would either neutralize the effects of part of the calcium sulphate or would react with some of the magnesium salts to lower the amount of "permanent" hardness. The amount of sodium chloride is so small as to be negligible in considering the value of the water.

In summing up the matter I will say that I think the flood flow of the united Santa Ynez and Mono will prove to be well within the limits set down by the most rigid eastern standards, and that from the available analyses even the low-stage flow will be found to be well within the limits allowable for western cities and much lower in salt contents than many waters which have been in use for a long time without deleterious effects.

If further analyses are made I would suggest that both "temporary" and "permanent" hardness be determined and that some attempt be made to collect flood samples as well as the normal and low stage from both streams.

In respect to the amount of solid matter in the stream, it will be seen that there was less silt in the first flood water from the Mono than from the Santa Ynez; the reverse may be expected under ordinary conditions. Both of these analyses show the percentage of wet silt by volume at the expiration of a short period of settlement. This determination of solid matter by volume gives an exaggerated idea of the way in which the silt might be expected to destroy the storage capacity of the reservoir, for it will compact as it settles in the reservoir and as other silt is deposited upon it. In this manner it will solidify into soil occupying from one-half to one-quarter of the space indicated by its volumetric determination. Later floods have shown less than one-tenth of 1 per cent of silt.

The way to meet the silt problem in the future will be by building

the dams higher when their storage capacity is impaired. The elevation of the bed of the creek at the Mono reservoir site is 1,440 feet; the capacity to the 1,530-foot elevation is 6,509 acre-feet. If the water level is raised 10 feet, or to the 1,540-foot elevation, the capacity will be increased 2,254 acre-feet, or 34.6 per cent. If we consider that the reservoir will lose as much as 2 per cent of its capacity annually by silting, or 34 per cent in seventeen years, the original capacity could be restored by raising this dam 10 feet in height at the end of that period of time. In a similar manner the capacity of the Gibraltar reservoir may be increased about 30 per cent by raising the crest 10 feet above the 155-foot elevation.

FOREST COVER.

The true and permanent solution of this silting problem lies in the protection and development of the forest and brush cover of this reserve. A valuable brush cover is shown in Pl. III, *B*. Under existing conditions the Los Prietos Y Najalayegua grant is wedged in between the Pine Mountain and Zaca Lake Forest Reserve and the Santa Ynez Forest Reserve, along the canyon of Santa Ynez River. This private grant is not only pastured to sheep and goats, but is also subject to attacks from fires originating thereon which can not be properly restrained. Sheep have been described as the hoofed locusts of the mountains. Their small feet cut up and pulverize the soil, destroying the plants and roots that might otherwise escape them. They are a menace almost equal to that of fire to every drainage basin in southern California which they enter. Arrangements, if possible, should be made looking toward the condemnation of this property in some way and its addition to the forest reserves above referred to. The board of water commissioners of Santa Barbara very wisely and properly have urged this matter with the Departments at Washington, and the forestry experts who have examined the region have favorably reported upon the action suggested.[a]

With a natural increase of vegetation and protection from the fires which have raged through this district for years past it is believed that the silt danger would be largely mitigated. This is a subject which should be followed up as one of vital importance, and but one solution should be permitted, to wit, the expulsion of the sheep from the drainage basin of the Santa Ynez and the protection of the forest and brush cover from fire. Otherwise the drainage basin is satisfactory. There are practically no human habitations within its borders above the proposed reservoir sites, and probably will be none in the near future, as the country is too mountainous and too inhospi-

[a] In December, 1903, after the above had been written, an Executive order included this grant in the forest reserve, an exchange of holdings having been arranged with the owner, and now the entire reservation, including the whole basin of the upper Santa Ynez, is known as the Santa Barbara Forest Reserve.

table to admit of agricultural pursuits. The greater portion of the basin is now included in forest reserves.

RESERVOIR SITES.

JUNCAL SITE.

Mr. George Wright made surveys of the Juncal reservoir site and determined the following capacities:

TABLE 14.—*Capacities of the Juncal reservoir site for various heights of dam.*

Height of dam in feet.	Million gallons.	Acre-feet.
50	350	1,074
75	705	2,164
100	1,050	3,222
125	1,437	4,410
150	1,877	5,760
175	2,352	7,218
200	4,000	12,276

It will be noted that with a dam 100 feet high the capacity of the Juncal reservoir is 3,222 acre-feet; with a 100-foot dam on the Mono reservoir site the capacity is 8,763 acre-feet. The Mono site, therefore, has 2.72 times the capacity of the Juncal, with the same height of dam. The Gibraltar dam, 100 feet high above stream bed, will hold 6,480 acre-feet. It is believed that the Juncal reservoir site alone will not furnish an adequate water supply to the city, but when used in connection with other reservoir sites having greater drainage areas above them it may be of value. The drainage area above the Juncal is but 13.4 square miles, not 23½ square miles as reported upon previously by other engineers. The length of a dam 200 feet high at the Juncal would be 550 feet on top, and a 100-foot dam would be 272 feet.

Mr. Purslow estimated that the cost of building a 100-foot dam and a riveted-steel pipe line (which latter must be considered as temporary construction) to Santa Barbara would be $282,450. He also states that the run-off from the drainage basin of the Juncal was measured in the winter of 1895–96 and that it amounted to 2,455 acre-feet. On the other hand, it is estimated in this report (see p. 53) that the run-off of the Juncal in 1895–96 was only 520 acre-feet from 13 square miles—a figure, therefore, apparently overconservative. However, there probably was a flood in January, 1896, as the rainfall for that month was 6.84 inches at Santa Barbara and probably 9 inches in the drainage basin of the Juncal. This may have produced a rather abnormal flood condition. As Mr. Purslow gives no details of his

work, not even the length of time of his observations, his results can not be accepted as conclusive.

Mr. Wright states that the rock at this dam site, which is quite similar to the formation prevailing throughout this region, weighs 149 pounds per cubic foot. In this estimate this rock has been considered as weighing 150 pounds per cubic foot, as determined at various points along the Coast Range by geologists. Masonry work made therefrom is taken to weigh 143 pounds per cubic foot.

MAIN RIVER SITE.

The Main River reservoir site was investigated by Mr. Purslow. This also was surveyed by W. B. Clapp for the Geological Survey. We find that a dam 65 feet in height would have a storage capacity of 1,311,000 gallons, or 4,023 acre-feet, to the 65-foot flow line. Figs.

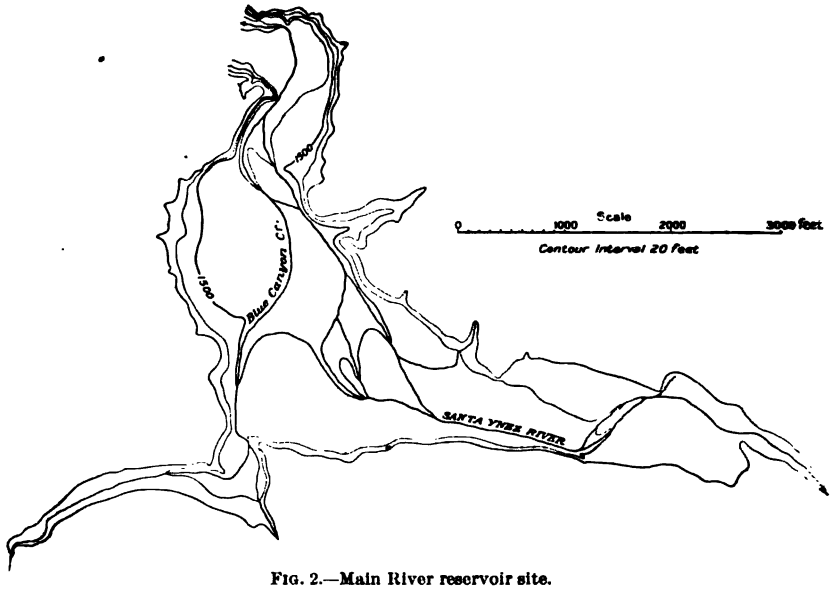

FIG. 2.—Main River reservoir site.

2 and 3 show the reservoir and dam sites. The Mono reservoir site with water held to the 75-foot level would have a capacity of 3,968 acre-feet. The Main River dam, however, would contain very much more masonry and be more expensive than the Gibraltar or the Mono dam. A dam 75 feet high at the Main River site would be 592 feet long on top and 427 feet long on the base. At the Mono dam site a dam 75 feet high would be 277.5 feet long on top and 150 feet long at the bottom. The Gibraltar is still more favorable. With an 85-foot rock-fill dam at the Mono the cost per acre-foot of capacity is $36, while at the Main River site with a 65-foot concrete dam the cost is about $154 per acre-foot of capacity, depending on depth of bed rock.

Mr. Purslow states that it would require a tunnel 15,500 feet long to pass through the Santa Ynez Range to the coast side and that the estimated cost of developing this work would be $557,000. It is believed that a shorter location can be found. The width of canyon covered by débris at the Main River dam site is so great and the depth to bed rock so uncertain that it is impossible to give even an approximate estimate of the cost of this dam. It must be of masonry, as it will have to be an overflow weir. If bed rock is taken as 25 feet below the bed of the creek, it may cost $620,000 for the dam alone.

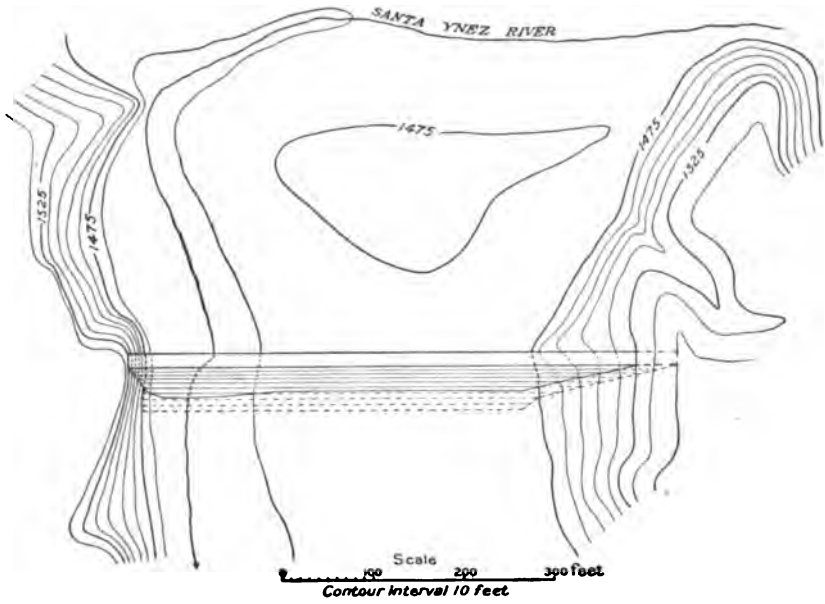

FIG. 3.—Main River dam site.

The effort has not been made in this report to go into the details of these estimates of cost for the Main River and Juncal reservoir sites. The reservoir sites are owned by the Santa Barbara City Water Company. It is believed, however, that if the city of Santa Barbara constructs a tunnel through the Coast Range, in order to lead the water from the lower reservoir sites to the city, the construction by some one of the Juncal or Main River reservoir sites may ultimately follow. This tunnel is a very large element in the cost of the work, and will require by far the greater length of time to construct. It must be so located as to permit the water from all the sites to be led through it by gravity to the coast, and its capacity must be sufficient to accommodate all of the water.

TABLE 15.—*Area and contents of Main River reservoir.*

[Survey by W. B. Clapp.]

Contour.	Acres.	Acre-feet between contours.	Total acre-feet to contour.	Capacity in millions of gallons.
1,460	0.33	.....	.....	.....
1,470	2.68	15.05	15.05	5
1,480	14.38	85.30	100.35	33
1,490	30.45	224.15	324.50	106
1,500	71.59	510.20	834.70	272
1,510	120.19	958.90	1,793.60	581
1,520	154.69	1,374.40	3,168.00	1,032
1,530	187.66	1,711.75	4,879.75	1,590
1,540	222.06	2,048.60	6,928.35	2,357
.....	.....	6,928.35	.....	

75-foot flow-line capacity=5,904.05 acre-feet.
Depth of bed rock unknown.

FIG. 4.—Mono reservoir site.

BLUE CANYON SITE.

The Blue Canyon reservoir site is situated in what is known as Blue Canyon, which discharges into the Santa Ynez a short distance above the Main River reservoir site. It is a good reservoir site, but as the drainage basin is only 8 square miles it is not considered feasible to fill it from its tributary natural-water supply. The Blue Canyon reservoir site is between Santa Ynez River and the crest of Santa Ynez Mountains. The length of tunnel from this reservoir site to the coast side would be 10,500 feet. To fill it from Santa Ynez River, in addition to building this long tunnel, would be too expensive a proposition to justify the construction.

MONO SITE.

A detailed and careful survey was made of the Mono reservoir and dam site by Mr. W. B. Clapp, of the hydrographic branch of the Geological Survey. Fig. 4 shows the results of these surveys, and Pl. IV, *B*, is a view of the site. The following table gives the capacity:

TABLE 16.—*Area and contents of the Mono reservoir site.*

[Survey by W. B. Clapp.]

Contour.	Area in acres.	Capacity in acre-feet between contours.	Total capacity in acre-feet.	Capacity in millions of gallons.
1,440.0	0	.....	.....	.....
1,450.0	1.2			
1,460.0	10.6	.....	[a] 94.0	.....
		59.0	.....	.....
1,461.2	.....	209.0	00.0	.....
1,470.0	31.2	.....	174.0	57
1,480.0	49.9	406.0	580.0	189
1,490.0	71.3	606.0	1,186.0	386
1,500.0	98.1	847.0	2,033.0	662
1,510.0	125.4	1,117.5	3,150.5	1,026
1,520.0	164.0	1,447.0	4,597.5	1,498
1,530.0	199.5	1,817.5	6,415.0	2,090
1,540.0	251.4	2,254.5	8,669.5	2,825

[a] Below outlet.

Total capacity in acre-feet	8,763.5
Capacity below outlet	94.0
Capacity, above outlet	8,669.5
Elevation of creek bed	1,440.0
Elevation of outlet	1,461.2

Depth of bed rock unknown.

This reservoir site has tributary to it a drainage area of 119 square miles. The creek passes first through a large flat and then through a narrow gorge. It is an unusually good reservoir site for southern California, but the dam site is poor. If the tunnel which the city is now running is continued at a grade of one-tenth of a foot rise to 100 feet horizontal, the elevation of the north portal of the tunnel on the datum plane that has been used will be 1,457.2 feet.[a] We may assume that a conduit leading from the reservoir site to the portal of the tunnel would descend approximately 4 feet in grade, giving an approximate elevation of the outlet from the reservoir as 1,461.2 feet, or 21.2 above the bed of the stream at the reservoir site. This is not of material consequence, as it is usually the case with reservoir sites that the first 20 or 30 feet above the bed of the stream at the dam site has very limited storage capacity. Thus the total storage capacity to the 100-foot flow line at the Mono reservoir site is 8,763.5 acre-feet and the capacity below the outlet is but 94 acre-feet, so that the net capacity above this outlet with a 100-foot dam would be 8,669.5 acre-feet, or 99 per cent of the total.

DISCHARGE.

Measurements of the flow of the Mono during the winter of 1902-3 were made daily, and the discharge for the season was found to be as follows:

TABLE 17.—*Estimated monthly discharge of Mono Creek at the dam site for season of 1902-3.*

[From daily measurements.]

1902.	Acre-feet.	1903.	Acre-feet.
July	0	January	676
August	0	February	389
September	0	March	1,845
October	0	April	4,820
November	173	May	799
December	12	June	220
		Season	8,934

The mean rainfall at Santa Barbara is 16.78 inches; for the last season it was 20.45 inches. Although the precipitation was in excess of the mean, the rainfall was not delivered in such manner as to produce large stream discharge and in the opinion of local residents the streams were below normal. The five preceding years were all below the mean in precipitation, so that a larger portion of the water than usual was absorbed by the ground. These measure-

[a] For more detailed statement, see p. 40.

ments of the streams should be continued so that the height of dam may be intelligently proportioned to the probable water supply. (See table 12, p. 53, showing estimated volumes of flow annually.)

CONTENTS AND COST OF DAMS.

Two types of dam for the Mono site have been considered. The rock on the sides of the canyon at this dam site is sandstone and shale, the stratification being practically vertical and the strike at right angles to the direction of the stream flow. Pl. IV, *A*, shows the character of this rock at the left abutment, which is the best. It weighs approximately 150 pounds to the cubic foot, and could be quarried in sizes and forms suitable for the work on the dam. The abutments are much better at the Mono dam site than at the Main River dam site, but not so good as at the Gibraltar. Spillway opportunities occur at the right abutment for the accommodation of flood discharges when the reservoir may happen to be full. The dam is considered in each instance to be 10 feet above the elevation of its spillway, so as to prevent the water overtopping the structure. The depth to bed rock is not known. The most serious item in connection with the construction of the dam is probably the transportation of supplies and materials to the site. In case the dam should be a cement, masonry, or concrete structure there would be a large amount of cement, which is a heavy material, to be hauled to the reservoir site. The masonry dam is believed to be the better form of construction, but because of considerations of economy the cost of the rock-fill type of dam has been computed.

These supplies for a rock-fill dam would probably be hauled by teams up Santa Ynez River from the end of the railroad at Ballard, a distance of 40 miles, or possibly through the tunnel when it is completed. The wagon road would be poor for the last 10 miles, but the grades easy. In the original estimate for this dam made for the city of Santa Barbara all material was considered as hauled by wagon to the dam site for both forms of structure. Since then (January 1, 1903) the manufacture of native cements has reduced the price of this constituent materially.

The rock-fill may be the better type for this point because of its greater economy. As the volume of material that would have to be brought in for construction purposes would be relatively small as compared with a masonry dam, it probably would not be advisable to provide for transportation through the tunnel for it, as would be necessary if a masonry dam were built. The estimates are therefore made upon this assumption. Fig. 5 shows a plan for a 110-foot rock-fill dam and fig. 6 a plan for a subsidiary earthen dam.

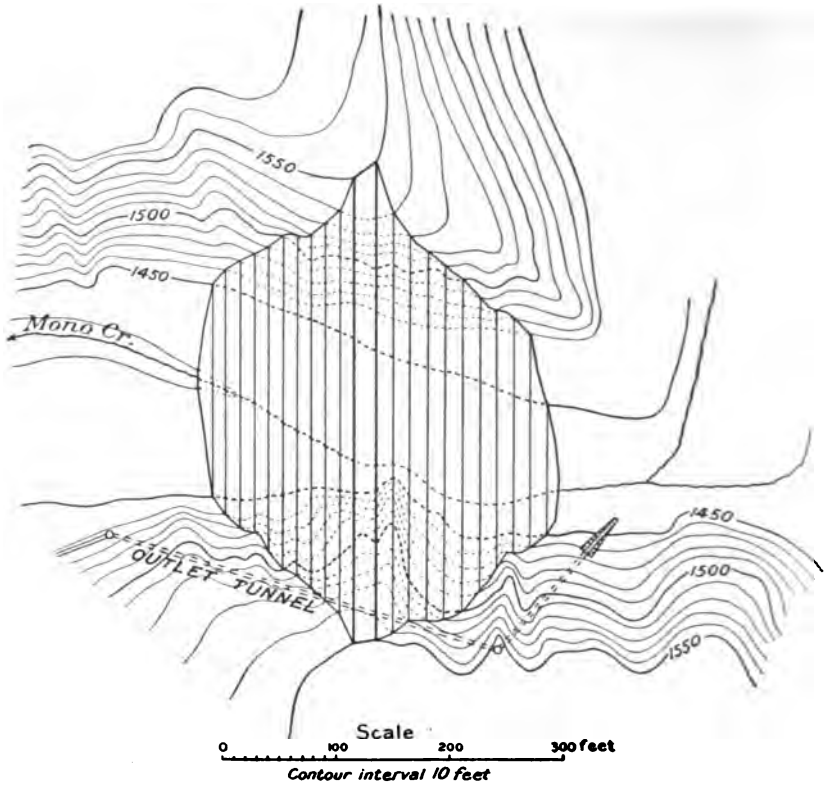

FIG. 5.—Mono dam site, showing 110-foot loose-rock dam.

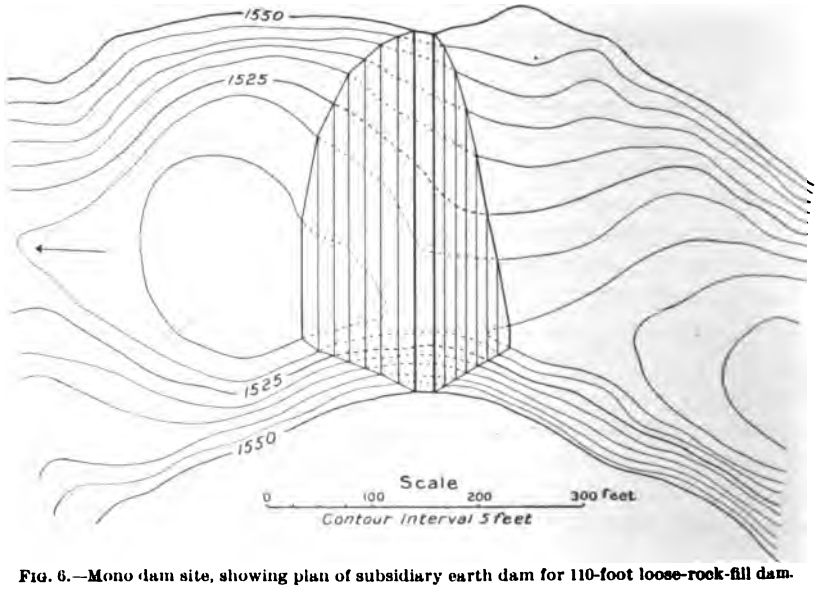

FIG. 6.—Mono dam site, showing plan of subsidiary earth dam for 110-foot loose-rock-fill dam.

All engineers connected with these investigations have declared that it is quite necessary, before preparing an accurate report and estimate on the reservoir sites, to know the position of bed rock at the place where the structure is to rest, and have recommended that these explorations should be carried out in connection with this present investigation. It has been found impossible, however, at this writing, to supply the funds to make this examination, and consequently the estimate must be taken with latitude in this regard.

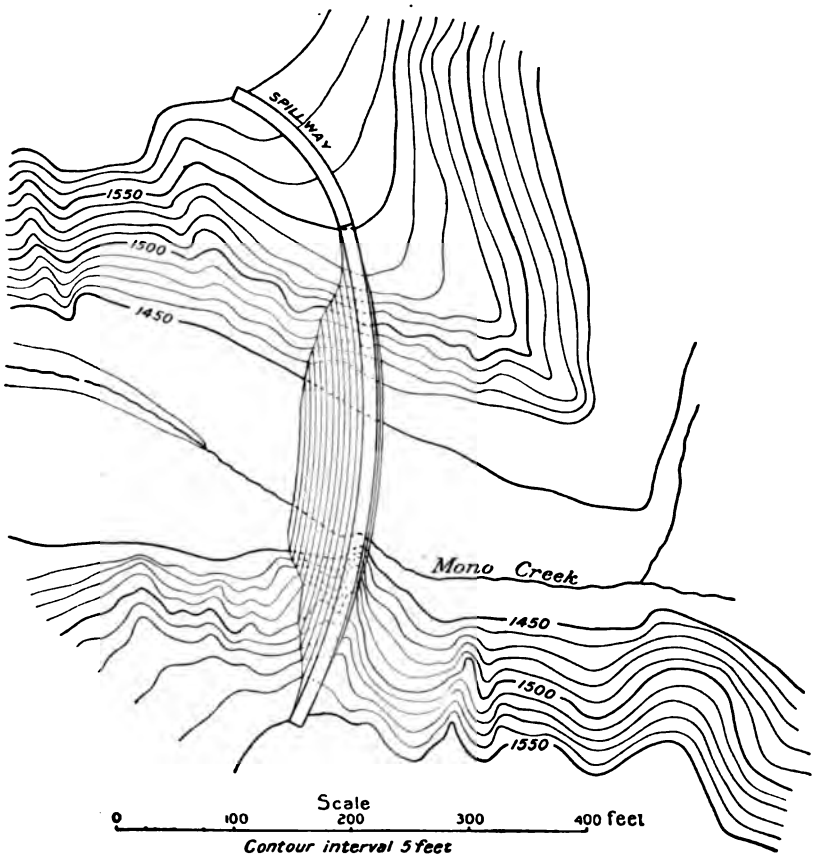

FIG. 7.—Mono dam site, showing plan for 110-foot concrete dam.

In the case of the rock-fill dam, it could rest properly and safely upon the present bowlder-covered bed of the canyon, but it would be necessary to carry down to bed rock on the upper slope an apron wall to cut off the underflow beneath the dam. This wall would be connected with a portion of the apron of the dam above ground in order to make it completely tight. It should be 8 feet thick at its base and 4 feet thick on top at the ground surface, so that for a loose-rock dam there would not be a great quantity of material to

be removed from the bed rock, and the amount of cement used would be small

In the case of a concrete or masonry dam, however, the whole structure would have to go down to the bed-rock foundation, which would have to be exposed and thoroughly cleaned. In estimating on the concrete dam it has been assumed that bed rock for the entire width of the canyon is 20 feet beneath the surface of the ground. At a point some 200 or 300 feet below the dam site a ledge of material projecting well out into the canyon, over which the stream flows, has the appearance of being bed rock or ledge matter in place. It is not known, however, whether it extends completely across the stream.

An 85-foot rock-fill dam at the Mono reservoir site would contain 75,480 cubic yards of loose rock, which, it is considered, could be quarried from cliffs that are favorably situated for $1 per cubic yard. Each yard, so thrown into the fill, would make 1¾ yards of fill; consequently a figure of 60 cents per cubic yard has been accepted. A dry-laid wall 2 feet in thickness on the upper face of the dam is provided for, upon which the asphalt-concrete apron will be laid. The upper toe wall is carried down to bed rock in the bed of the stream, 4 feet thick on top, 8 feet at base, and 20 feet high. On the sides of the dam this wall is also estimated upon to seal the asphalt-concrete to the abutments. The asphalted concrete will be put on 1½ feet thick, of broken stone, gravel, sand, and asphalt, the latter being brought from quarries on the lower Santa Ynez. The section of this dam will be 20 feet wide on top, with a very flat slope of 1½ feet horizontal to 1 foot vertical on the upper face and 1¼ feet to 1 foot on the lower face. This flat slope is given to the upper face so that there will be no movement in the asphalt apron. The asphalt also would be rammed into the crevices of the dry-laid wall on which it rests.

The spillway provisions are of vital importance in a rock-fill dam. The maximum flood that was ever measured on Sweetwater River since the dam was constructed there, some fifteen years ago, was 98 cubic feet per second for each square mile of the drainage basin. A flood discharge of Piru Creek was measured at Henderson's ranch on December 18, 1894, of 43 cubic feet per second per square mile of drainage area. On Arróyo Seco, a tributary of the Salinas in Monterey County, on November 21, 1900, a flood of 140 second-feet per square mile was observed. The rainfall, however, in the drainage basin of Arroyo Seco is exceedingly heavy. For the purposes of this report we have assumed a flood of 130 second-feet per square mile of drainage area, or a total flood discharge of 15,470 second-feet, filling the spillway to within 3 feet of the top of the dam. Before the spillway would be filled to the top of the dam the flood would have reached

26,420 cubic feet per second, or 222 second-feet per square mile of drainage basin. The spillway would be 251 feet long and the bottom of it would be 10 feet below the crest of the dam. It would be excavated from the rock at the right abutment of the dam.

A 20-inch pipe has been estimated upon, leading from the Mono reservoir site to the intake of the long tunnel through Santa Ynez Range of mountains. The aggregate cost of reservoir and pipe line to long tunnel is $140,700, or $36 per acre-foot of capacity.

In estimating upon the length of tunnel line through the Coast Range to this reservoir site we have accepted the present tunnel site and assumed that the tunnel is to be completed on an angle line, or in such manner as to avoid the property of all owners other than the city of Santa Barbara. On this basis there would still be 15,006 linear feet of tunnel to run, at an estimated cost of $12 per linear foot.

Estimate for 85-foot rock-fill dam at Mono reservoir site.

[Capacity 3,880 acre-feet.]

DAM.

75,480 cubic yards of loose rock, at 60 cents per yard	$45,288	
2,500 cubic yards of dry-laid wall (upper face), at $1 (extra)	2,500	
Upper toe and side wall to bed rock	16,500	
Asphalt-concrete face 1½ feet thick, 1,861.2 cubic yards, at $8	14,890	
Outlet tunnel, gates, and tower	10,000	
Spillway	20,000	
Clearing reservoir	2,460	
20-inch pipe line to long tunnel 7,000 feet from reservoir, capacity 189 inches	10,710	
Engineering, 5 per cent	6,117	
Contingencies, 10 per cent	12,235	
Total ($36 per acre-foot)		$140,700

TUNNEL.

15,006 linear feet of tunnel through Santa Ynez Range, via angle line, at $12 per foot	$180,072	
Road up Santa Ynez River	5,000	
Engineering, 5 per cent	9,254	
Contingencies, 10 per cent	18,507	
Total		212,833
Grand total		353,533

An estimate is also presented of the cost of building a rock-fill dam at the Mono to an elevation of 110 feet above the bed of the stream, impounding the water to the 100-foot flow line. The conditions would be the same for the construction of this dam as in the case of the 85-foot dam, except that a second small earthen dam would have to be built to close another opening; this is referred

to as the subsidiary dam. With the rock-fill type of dam it would be quite feasible to increase the height, raising the dam to such new elevation as might be desired.

Estimate for a 110-foot rock-fill dam at Mono reservoir site.

[Capacity 8,670 acre-feet, 290 miner's inches constant flow.]

142,535 cubic yards of loose rock, at 60 cents per yard	$85,521	
3,733 cubic yards of dry-laid wall, at $1 (extra)	3,733	
Upper toe and side walls	18,099	
Asphalt-concrete face 1½ feet thick, 2,772 cubic yards, at $8	22,176	
Outlet tunnel, gates, and tower	10,000	
Spillway	20,000	
Clearing reservoir, 257 acres, at $15	3,855	
Pipe line to long tunnel, 7,000 linear feet, capacity 366 inches	12,880	
25,745 cubic yards earth in subsidiary dam	7,724	
Engineering, 5 per cent	9,199	
Contingencies, 10 per cent	18,399	
Total ($24.40 per acre-foot)		$211,586
Tunnel through Santa Ynez Mountains, as above		212,833
Grand total		424,419

An estimate is also given for a masonry dam 85 feet high at the Mono reservoir site. This dam would be 12 feet wide on top, with a slope of 2 to 1 on the lower side and 20 to 1 on the upper side. The masonry would be made of hydraulic cement, which would be hauled through the finished tunnel. The outlet, tower, spillway provisions, and clearing reservoir would be the same as in the case of the rock-fill dam. The total cost of a dam of this class, including the 20-inch pipe line to the long tunnel, would be $361,690, or $93 per acre-foot of storage capacity. It thus will be seen that the masonry dam 85 feet high would cost 2.6 times what the loose-rock dam would cost. This is because the latter would be built of material at hand.

Estimate for 85-foot masonry dam at the Mono reservoir site.

[Capacity, 3,880 acre-feet.]

6,612 cubic yards masonry below surface of ground, at $15 (includes excavation)	$99,180	
22,955 cubic yards masonry above ground	172,163	
Total for dam proper		$271,343
Outlet tunnel, gates, and tower		10,000
Spillway		20,000
Clearing reservoir		2,460
7,000 feet of 20-inch conduit, capacity 189 inches		10,710
Engineering, 5 per cent		15,726
Contingencies, 10 per cent		31,451
Total		361,690

Cost per acre-foot of capacity, $93.

QUICKSILVER MINE DAM SITE, RIGHT ABUTMENT.

QUICKSILVER MINE RESERVOIR SITE.

View upstream from dam site.

QUICKSILVER MINE SITE.

A site called the Quicksilver mine reservoir site was discovered about 4 miles below the mouth of the Mono. At this point the river

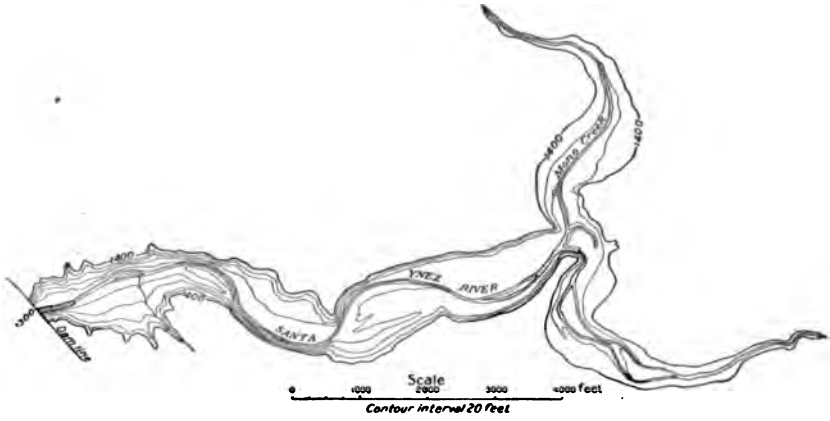

FIG. 8.—Quicksilver mine reservoir site.

passes through a rather narrow canyon of shale rock, shown in Pl. VI. The site itself is shown in Pl. VII. The capacity of this reservoir is

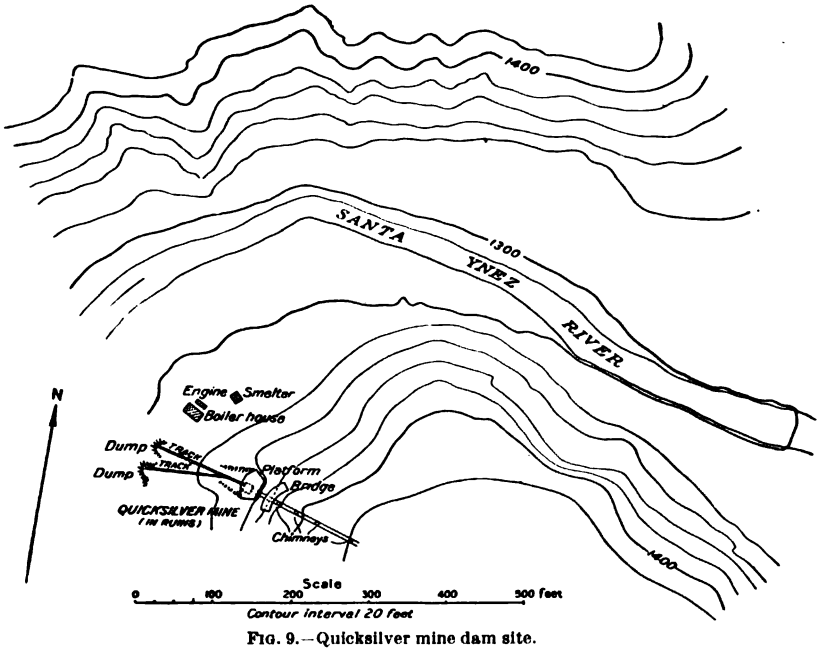

FIG. 9.—Quicksilver mine dam site.

large, but the dam site is not satisfactory because of the absence of suitable building material, and also on account of the character of the abutments. Figs. 8 and 9 show the reservoir and dam sites.

Water impounded to a depth of 100 feet in this reservoir would be flooded back a short distance into the Mono and up the Santa Ynez above the mouth of the Mono. The following is a table of the capacity of this reservoir.

TABLE 18.—*Capacity of Quicksilver mine reservoir site.*

Contour.	Area in acres.	Average area in acres.	Capacity in acre-feet.	
			Between contours.	Total to contours.
1,300	0.57	3.70	37.0	37.0
1,310	6.83	12.05	120.5	157.5
1,320	17.28	26.15	261.5	419.0
1,330	35.01	45.66	456.6	875.6
1,340	56.31	74.02	740.2	1,615.8
1,350	91.73	112.07	1,120.7	2,736.5
1,360	132.42	143.55	1,435.5	4,172.0
1,370	154.69	172.71	1,727.1	5,899.1
1,380	190.74	212.15	2,121.5	8,020.6
1,390	233.56	255.69	2,556.9	10,577.5
1,400	277.82			

The Quicksilver mine reservoir site, while of satisfactory capacity, is not considered a feasible proposition because of the character of the dam site.

GIBRALTAR SITE.

DISCHARGE.

The Gibraltar reservoir site is situated 6 miles below the mouth of Mono Creek on Santa Ynez River. The drainage area tributary to it includes all of the Mono, the main river above the Mono, and 17 square miles additional. The discharge as estimated from the rainfall for the seasons from 1867–68 to 1903–4, inclusive, is shown in table 12 (see p. 53), and as measured[a] for 1902–3 in table 13 (see p. 54). From these it appears that the discharge is from 1.8 to 2.4 times as great as that of the Mono.

CONTENTS AND COST OF DAMS.

The reservoir site, which is shown in fig. 10, lies along a narrow, canyon-like valley with a light grade. The dam site is a rather peculiar and unusual one. An anticlinal fold of sandstone, apparently uplifted through the shales, has been cut by the river in a narrow gorge, as shown in Pl. VIII, *A* and *B*. The crest of this fold is almost level and

[a] Partly estimated.

A. GIBRALTAR DAM SITE, LOWER END OF GORGE.

View upstream.

B. GIBRALTAR DAM SITE, UPPER END OF GORGE AT PROPOSED AXIS OF DAM.

View downstream. Stream turns abruptly to the left. The spillway site is over the crest on the left.

is approximately 150 feet above the bed of the stream, so that a dam built slightly higher than the crest, or, say, 155 feet, will have the advantage of a natural spillway of great length on the side away from the dam and over solid rock. This is the only dam site that has been found in the upper portions of Santa Ynez River where the abutments are of a satisfactory nature and where the building material could be gotten out in such sizes and shapes as may be desirable for the construction of any type of dam.

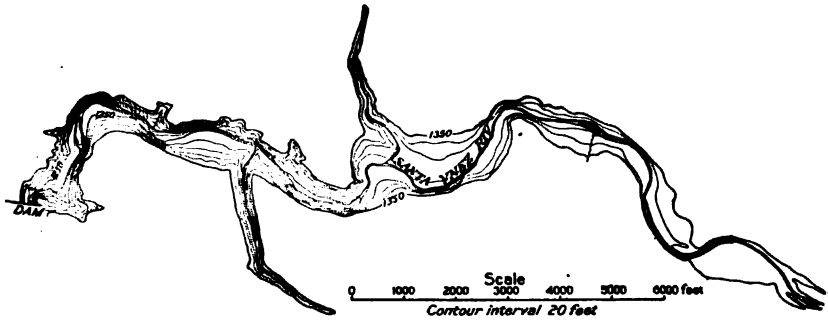

FIG. 10.—Gibraltar reservoir site.

A determination of the specific gravity of this rock has been made by weighing the rock first in air and then in water, which gave a specific gravity of 2.56. Four tests were made, ranging from 2.55 to 2.57. This is equivalent to a weight of 160 pounds per cubic foot. In rubble masonry, one-third of the bulk being mortar and two-thirds solid rock, and the mortar being considered as weighing 103 pounds, the weight would be 140 pounds per cubic foot of masonry in dam.

The ledges are in such a position as to permit a most economical handling of material for masonry construction.

TABLE 18a.—*Capacity of Gibraltar reservoir site.*

[Elevation of surface of stream bed, 1,215 feet.]

Contour.	Area in acres.	Average area in acres.	Capacity in acre-feet.	
			Between contours.	Total to contours.
1,215	0	.....	.....	.....
1,220	2.12	.....	.....	.....
1,230	5.74	3.93	39.3	39.3
1,240	13.26	9.50	95.0	134.3
1,250	22.67	17.97	179.7	314.0
1,260	32.37	27.52	275.2	589.2
1,270	50.11	41.24	412.4	1,001.6
1,280	66.24	58.17	581.7	1,583.3
1,290	90.06	78.15	781.5	2,364.8
1,300	119.62	104.84	1,048.4	3,413.2
1,310	152.74	136.18	1,361.8	4,775.0
1,320	188.33	170.53	1,705.3	6,480.3
1,330	227.13	207.73	2,077.3	8,557.6
1,340	271.39	249.26	2,492.6	11,050.2
1,345	296.64	284.01	1,420.0	12,470.2
1,350	332.75	314.70	1,573,5	14 043.7
1,355	367.07	349.91	1,749.6	15,793.3

Table 19 shows the volumes of material for a rock-fill dam situated at the Gibraltar reservoir site, the upper slope to be 1½ to 1, the lower slope 1¼ to 1, the width on top 20 feet, and the height of dam 155 feet, or 10 feet above the level of the spillway. The top of the crest is taken to be at the 1,360-foot contour. Bed-rock conditions are unknown, but for the purpose of this estimate are assumed to be at 1,205 feet. Repeated efforts were made to provide for an exploration of bed rock at this dam site, but owing to financial condi ions and negotiations for the purchase of the property by the city of Santa Barbara it was not possible to arrange for this. The capacity with this dam to the 1,350-foot contour in the reservoir would be 14,044 acre-feet. Fig. 11 shows the plan for a 155-foot rock-fill dam.

In the table 7,444 cubic yards are deducted from the total estimated volume in the dam, as the rock fill will go down only to the 1,210-foot contour, except where the toe walls are located, where they are assumed to go as low as the 1,205-foot contour. The excavation of the spillway is taken at 1,250 cubic yards, which of course would be used in the construction of the dam. The spillway could probably

be made much wider, if desired, in excavating the material for the dam. In this estimate it is taken as 350 feet in width.

A dam of this type is considered as having 12,083 cubic yards in asphalt-concrete face and dry-laid wall, this face to be put on as indicated in the drawing and to be covered by the dry-laid wall, to

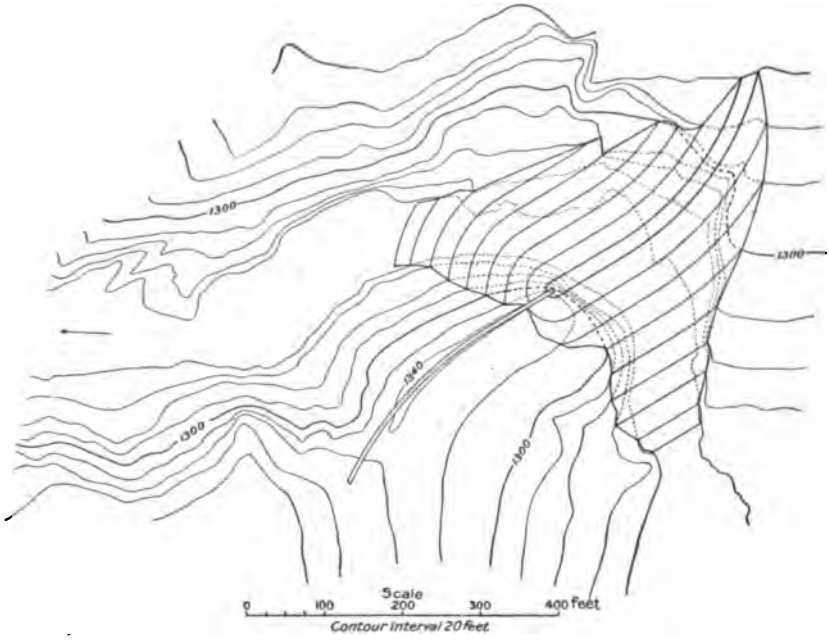

FIG. 11.—Gibraltar dam site, showing plan for 155-foot rock-fill dam.

protect it from the sun, so as to prevent the movement of the asphalt. If this volume is deducted from the total yardage given in the dam, in addition to the deduction mentioned above on account of the rock-fill dam not going down to bed rock for its entire length, the net volume of rock fill will be 233,724 cubic yards.

TABLE 19.—*Volume in rock-fill dam at Gibraltar dam site.*[a]

[Capacity to 1,350-foot contour, 14,044 acre-feet.]

Contour.	Volume between contours in cubic yards.	Contour.	Volume between contours in cubic yards.
[b]1,205	.....	1,320	15,231
1,210	7,444	1,330	13,194
1,220	14,713	1,340	10,916
1,230	16,648	1,350	8,148
1,240	19,805	1,360	4,796
1,250	21,536	Total	253,251
1,260	22,185	Deduct[c]	7,444
1,270	21,860		245,807
1,280	20,925	Deduct[d]	12,083
1,290	19,981	Net	233,724
1,300	18,768		
1,310	17,101		

[a] Contents of spillway masonry dam—1,250 cubic yards. Spillway dam, 5 feet wide on top; 0.05 to 1 slope on upstream face; 10 feet down, 7 feet thick; 15 feet down, 9 feet thick; 20 feet down, 13 feet thick. Spillway is 350 feet in width; in excavating for dam it may be made wider, the limit in width being the limit of excavations.
[b] Bed rock as estimated, but not determined.
[c] Rock fill goes only to 1,210-foot contour.
[d] Asphalt face and dry-laid wall.

The hand-laid facing on top of the asphalt-concrete is estimated to be 3½ feet thick and the asphalt-concrete 1½ feet, covered with an impervious layer of asphalt two-tenths of a foot thick. The concrete cut-off wall at the upper toe of the dam is estimated as 90 feet long, with a height above assumed bed rock of 5 feet and a thickness on top of 5 feet, downstream vertical, upstream with a slope of 1 to 5 and a thickness at base of 6 feet.

The outlet system would consist of a tower reaching from the 1,220-foot contour to the 1,360-foot contour, a height of 140 feet. The internal diameter of the tower would be 8 feet at top and the thickness of wall 2 feet at top and 6 feet at bottom, the tower standing on a solid concrete base 5 feet thick and 21 feet in diameter. Following is an estimate of the cost:

Estimate of cost of 155-foot rock-fill dam at original site of Gibraltar dam.

Rock fill, 233,724 cubic yards, at 60 cents	$140,234.00
Hand-laid facing, 8,458 cubic yards, at $1.60	13,533.00
Asphalt and concrete facing, 3,625 cubic yards, at $8	29,000.00
Cut-off wall	1,493.00
Overflow weir and subsidiary dam, 1,250 cubic yards, at $9	11,250.00
Clearing reservoir site, 333 acres, at $25	8,325.00

Outlet system:		
Tower, 911 cubic yards, at $9.30	$8,472.00	
Inlet pipes	460.00	
Valve rods	860.00	
Outlet valves	1,000.00	
Outlet tunnel, 1,000 feet, at $5	5,000.00	
Tower house and bridge	500.00	
Total of outlet system		$16,292.00
		220,127.00
Contingencies, 10 per cent		22,012.70
Engineering, 5 per cent		11,006.35
Total		253,146.05

The rock-fill dam can be built only to such height as will permit complete spillway opportunities around the end of the dam. It is, however, feasible to build a masonry dam that will not be the full height, permitting the water to waste over the top of the dam during different stages of its construction. For instance, the dam could be built to a height of 50 or 100 feet, and construction stopped until the demands or desires of the city should call for its completion; the final structure could then be built to its ultimate height of approximately 155 feet. When the dam was completed to its full height the overflow and waste water could then be directed through the spillways.

If such a dam should be built of cyclopean rubble masonry on a gravity section and also on a curve, the top would stand at the 1,560-foot contour. The estimate given below is based on bed rock being at a depth of 5 feet beneath the present stream bed, but it is not known what the depth actually is, and the final estimates might be greatly modified by these conditions. A determination of this point is essential before beginning the construction of the dam and before the final estimate on its cost can be made.

Three estimates have been prepared on the assumption that the dam will not be built to its full height from the start. These are for dams 95 feet high, with a capacity of 3,413 acre-feet, equivalent to a continuous flow of 4.715 second-feet, or 236 miner's inches per annum; 125 feet high, with a capacity of 8,558 acre-feet, equivalent to a continuous flow of 11.82 second-feet, or 591 miner's inches per annum; and 155 feet high, with a capacity of 15,793 acre-feet, equivalent to a continuous flow of 21.81 second-feet, or 1,090 miner's inches per annum.

These estimates of discharge are on the assumption that the reservoir would be filled by the stream every year. This, however, can not be done, for in some winters there will be little more addition to the reservoir than enough to make up for evaporation. If it is assumed that the 155-foot dam is built, and that its capacity is

15,793 acre-feet, and that this will have to furnish the supply of water for nineteen months, the yield will be 831 acre-feet monthly; with the reservoir half full the monthly loss by evaporation would average about 66 acre-feet, leaving 765 acre-feet monthly for distribution during the dry period, or a continuous flow of 13 second-feet, equivalent to 650 miner's inches, or 8,400,000 gallons daily. Putting it another way, the flow will be approximately 900 miner's inches in the summer time and 400 miner's inches in the winter time. Fig. 12 shows a plan of a 155-foot masonry dam.

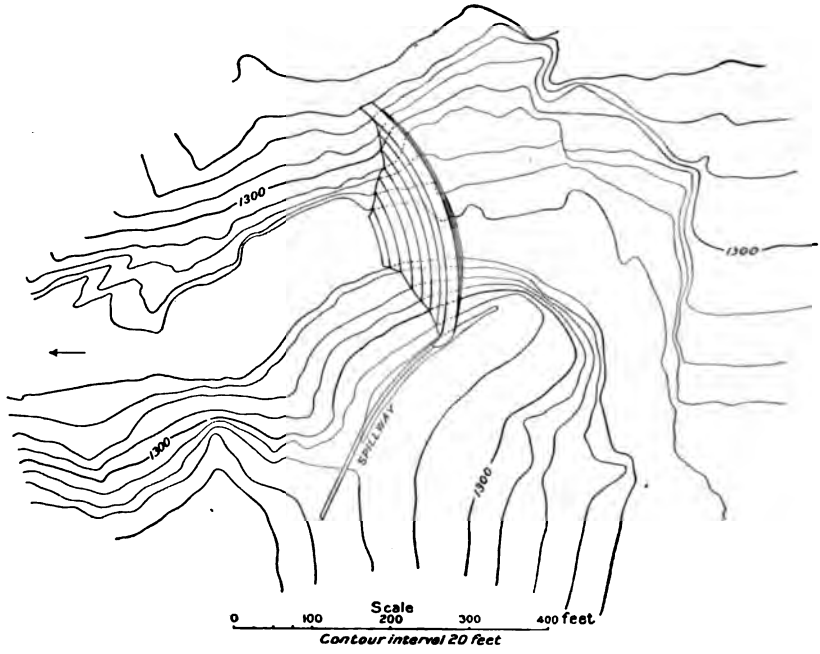

FIG. 12.—Gibraltar dam site, showing plan for 155-foot masonry dam.

With the lower size dam the surplus water is considered as wasted over the top of the dam, and the dam is made safe on the gravity section with 10 feet of water passing over its crest; in addition it is to be a curved dam. These same conditions will obtain with a dam 125 feet high. The 155-foot masonry dam is designed to let the surplus water pass through a spillway, the water standing within 5 feet of the top of the dam, and the capacity being 15,793 acre-feet. This is a greater capacity than that for the 155-foot rock-fill dam, because with the rock-fill dam greater safety in spillway capacity would be required, and this type would have to be built at least 10 feet above the level of the spillway. Figs. 13, 14, and 15 give sections of the dams considered. In the estimates masonry weighing 140 pounds per cubic foot is used.

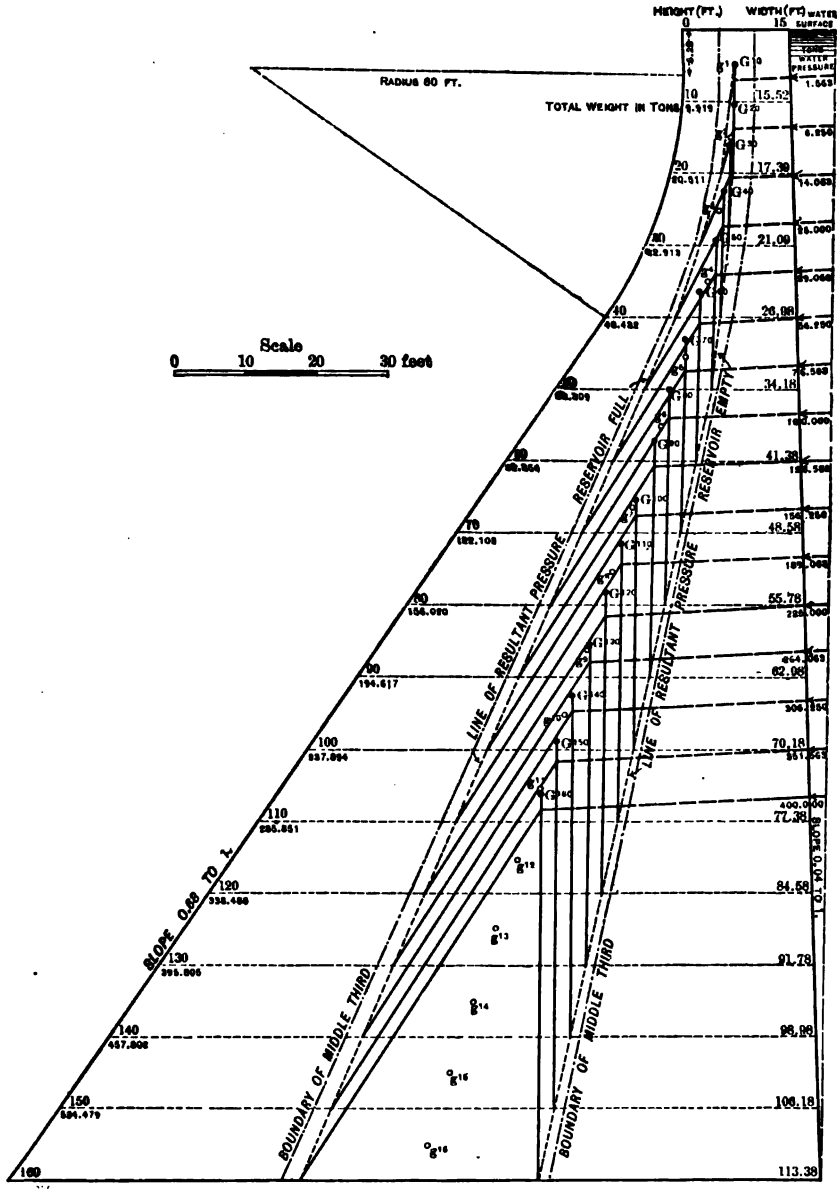

FIG. 13.—Section of masonry dam for Gibraltar reservoir based on concrete weighing 130 pounds per cubic foot.

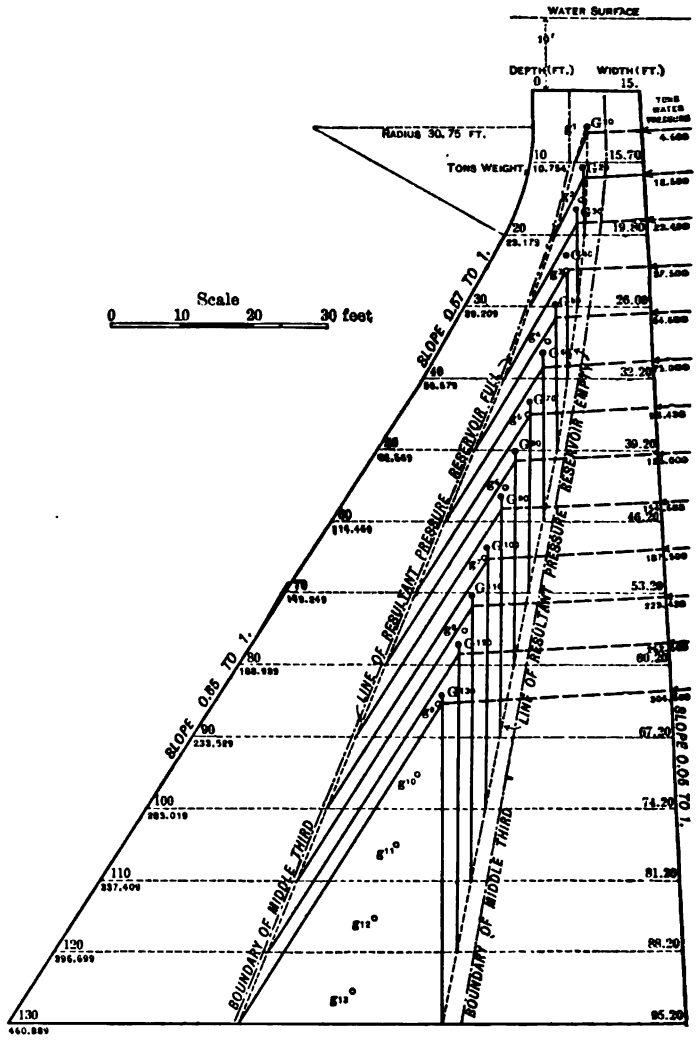

FIG. 14.—Section of masonry overflow weir dam based on masonry weighing 140 pounds per cubic foot.

The following is an estimate on three types of dams:

Estimate of cost of 95-foot masonry overflow dam located at lower site of Gibraltar dam.

[Capacity 3,413 acre-feet.]

Masonry, 15,331 cubic yards, at $7	$107,317.00
Excavation to bed rock, 1,280 cubic yards, at $2.50	3,200.00
Clearing reservoir, 120 acres, at $25	3,000.00
Outlet system, tower, gates, tunnel, etc	9,971.00
	123,488.00
Contingencies, 10 per cent	12,348.80
Engineering, 5 per cent	6,174.40
Total	142,011.20

Cost per acre-foot of capacity, $41.61.

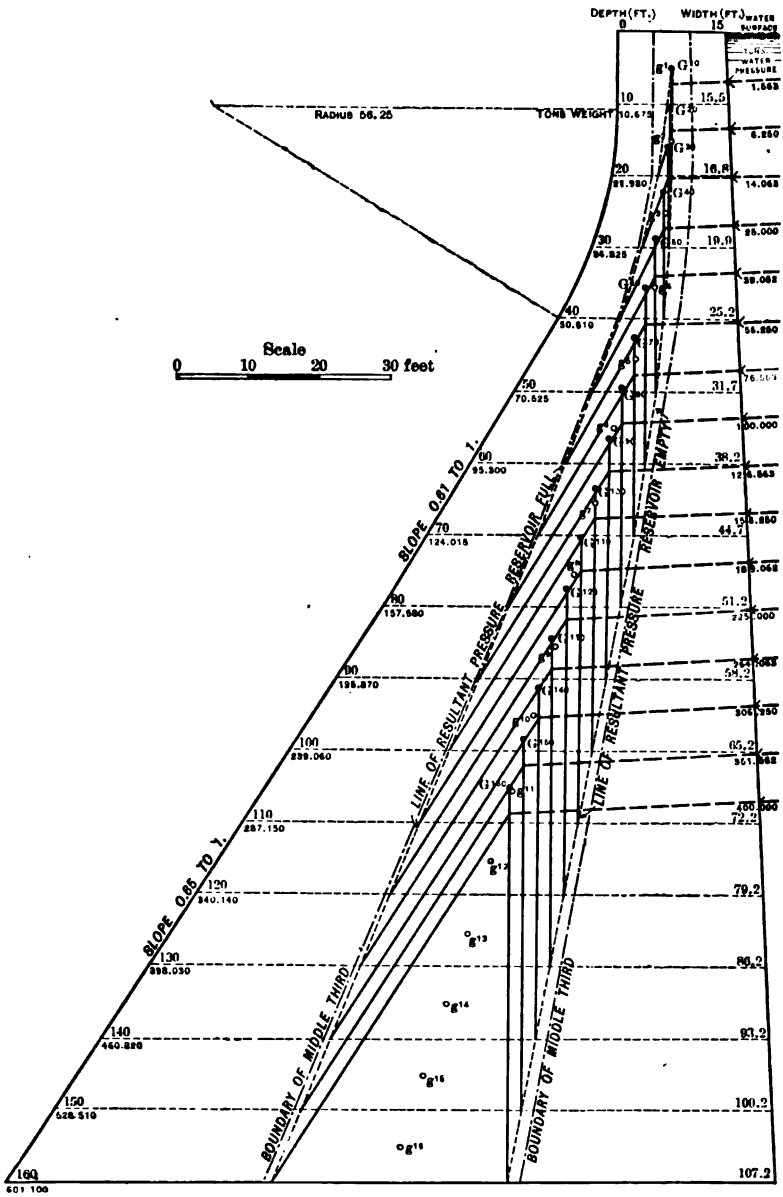

FIG. 15.—Section of masonry dam based on masonry weighing 140 pounds per cubic foot.

Estimate of cost of 125-foot masonry overflow dam located at lower site of Gibraltar dam.

[Capacity 8,558 acre-feet.]

Masonry, 27,971 cubic yards, at $7	$195,797.00
Excavation to bed rock, 1,579 cubic yards, at $2.50	3,948.00
Clearing reservoir, 227 acres, at $25	5,675.00
Outlet system, tunnel, gates, tower, etc	13,000.00
	218,420.00

Contingencies, 10 per cent	$21,842.00
Engineering, 5 per cent	10,921.00
Total	251,183.00

Cost per acre-foot of capacity, $29.35.

Estimate of cost of 155-foot masonry dam located at lower site of Gibraltar dam.

Masonry in dam, 42,250 cubic yards; masonry in spillway, 833 cubic yards; masonry in protection wall, 56 cubic yards; total masonry, 43,139 cubic yards, at $7	$301,973.00
Excavation to bed rock, 1,731 cubic yards, at $2.50	4,328.00
Clearing reservoir, 350 acres, at $25	8,750.00
Outlet system, tower, gates, tunnel, etc.	16,292.00
	331,343.00
Contingencies, 10 per cent	33,134.30
Engineering, 5 per cent	16,567.15
Total	381,044.45

The flood discharge from these drainage basins is considered in the discussions of the spillway for the Mono reservoir site. Taking a maximum flood discharge of 130 cubic feet per second per square mile from the entire 207 square miles that are tributary to the Gibraltar reservoir site, the spillway of 600 feet in length would be running full and the water passing 3½ feet deep over the top of the masonry dam. This would be a most extraordinary flood, and it is believed that the dam, with the gravity section that it has, in addition to its arched shape, would stand this.

In the case of the 125-foot dam such a flood would pass over the crest of the dam 9½ feet deep, and the dam is designed to withstand with safety an overflow of 10 feet on a gravity section without the aid of its curved shape.

For the 95-foot dam under similar conditions the depth of water would be 11 feet.

TUNNELS TO GIBRALTAR SITE.

Because of its elevation and location it will not be possible to use the old city tunnel in Cold Spring Canyon in reaching the Gibraltar reservoir site. The elevation of the surface of the water at the Gibraltar, with a dam 155 feet high, is 1,360 feet above sea level, and the estimated elevation of the northern end of the old Cold Spring Canyon tunnel at its northern portal would be 1,457 feet. The location also is not suitable for the Gibraltar site. Because of these facts, a new tunnel location was sought as an outlet for the Gibraltar reservoir site. The triangulation was extended so as to cover the distance intervening between Mission Canyon and the Gibraltar dam site, and it was found that a tunnel from Mission Canyon to the Gibraltar would be 19,560 feet in length, and from Rattlesnake Canyon to the

Gibraltar it would be 20,763 feet in length. The length necessary to complete the old tunnel from Cold Spring Canyon through to Santa Ynez is 14,901 feet. It must be remembered, however, that the old tunnel has very irregular grades, that the cross section of it is not uniform, and that the alignment is irregular. In addition to that, the present heading is 5,000 feet from the portal, so that the total length of the Cold Spring Canyon tunnel, if completed, would be 19,901 feet. Because of these irregularities in the old tunnel and the dis-

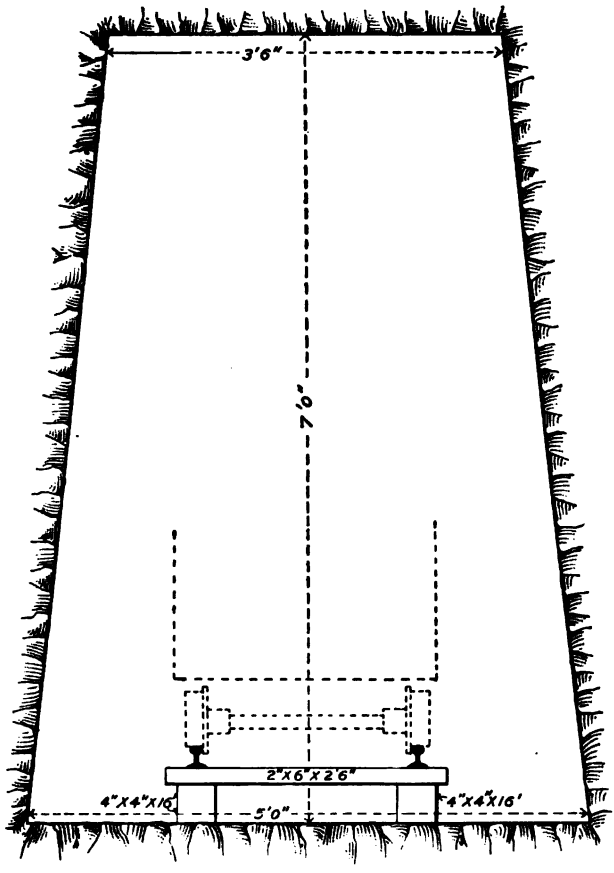

FIG. 16.—Section of new Santa Barbara tunnel in solid rock.

tance in from the heading, it has been estimated that the cost to complete it would be at the rate of $12 a foot; the total cost of completing it, building roads, engineering, etc., having been previously estimated at $212,833 (see p. 77).

The following is an estimate of the cost of building the Mission or the Rattlesnake tunnel.[a]

[a] Since writing the above, contracts have been entered into for the construction of the Mission Canyon tunnel line at a figure slightly below this estimate (see p. 43). Figs. 16 and 17 show sections of this tunnel.

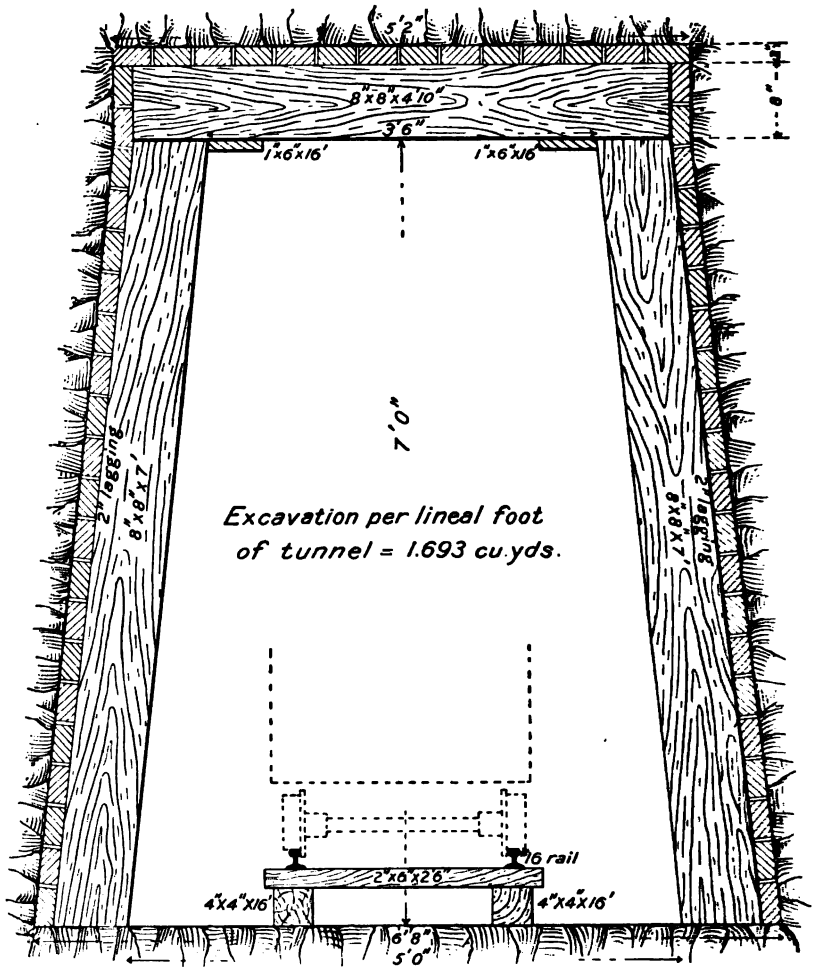

FIG. 17.—Section of new Santa Barbara tunnel in loose rock.

Estimate of cost of building Mission Canyon tunnel.

[Length based on triangulation by L. M. Hyde.]

19,560 linear feet, at $10 per linear foot	$195,600
Road up Santa Ynez River	2,500
Road up Mission Canyon	2,500
Engineering, 5 per cent	10,030
Contingencies, 10 per cent	20,060
Total estimated cost	230,690

Estimate of cost of building Rattlesnake Canyon tunnel.

[Length based on triangulation by L. M. Hyde.]

20,763 linear feet, at $10 per linear foot	$207,630
Road up Santa Ynez River	2,500

Road up Rattlesnake Canyon	$3,500
Engineering, 5 per cent	10,682
Contingencies, 10 per cent	21,363
Total estimated cost	245,675

COMPARISON OF GIBRALTAR AND MONO SITES.

In order to compare the costs of the combined tunnel and reservoir for the Gibraltar site and for the Mono site, the following table is given:

TABLE 20.—*Comparative estimates of dams and tunnel lines at Gibraltar and Mono.*

GIBRALTAR.	
95-foot masonry overflow dam (3,413 acre-feet, at $41.61)	$142,012
19,560 feet of tunnel (Mission line)	230,690
Total	372,702
125-foot masonry overflow dam (8,558 acre-feet, at $29.35)	251,183
19,560 feet of tunnel (Mission line)	230,690
Total	481,873
155-foot masonry dam (15,793 acre-feet, at $24.13)	381,044
19,560 feet of tunnel (Mission line)	230,690
Total	611,734
155-foot rock-fill dam (15,793 acre-feet, at $16.02)	253,146
19,560 feet of tunnel (Mission line)	230,690
Total	483,836
MONO.	
85-foot rock-fill dam (3,880 acre-feet, at $36)	140,700
15,006 feet of tunnel	212,833
Total	353,533
110-foot rock-fill dam (8,670 acre-feet, at $24.40)	211,586
15,006 feet of tunnel	212,833
Total	424,419
85-foot masonry dam (3,880 acre-feet, at $93.22)	361,690
15,006 feet of tunnel	212,833
Total	574,520

The masonry dam is the better form of construction for a storage reservoir. In addition the abutments at the Gibraltar reservoir site are much more secure and satisfactory than at the Mono site. The water supply is more than twice as great at the Gibraltar as at the Mono and its quality is better.

Making the comparison for masonry dams, it will be seen that the cost for the 155-foot masonry dam at the Gibraltar site would be

$24.13 per acre-foot of water impounded, while for the 85-foot masonry dam at the Mono site it would be $93.22 per acre-foot.

With a 125-foot masonry dam at the Gibraltar, the capacity of the reservoir would be 8,558 acre-feet, and the total estimated cost of the dam and tunnel would be $481,873.

A 110-foot rock-fill dam at the Mono would have a capacity of 8,676 acre-feet, and with the completion of the Cold Spring tunnel would cost $424,419, which is less than the cost of the Gibraltar 125-foot dam. The Gibraltar dam, however, would undoubtedly be safer, have fully twice the water supply available for dry years, and would furnish better water. These things considered, there can be no doubt whatever that it is advisable to construct the Gibraltar dam with the Mission Canyon tunnel, rather than the Mono site with the completion of the Cold Spring Canyon tunnel.

The real governing factor in the entire situation is the quantity and quality of the water, and on this basis there can not be any doubt that the Gibraltar site is far the better. During the winter of 1902–3 the total discharge of Mono Creek at the Mono reservoir site was 8,934 acre-feet, while at the Gibraltar it was 21,202 acre-feet, or 2.4 times as much. In addition the situation is such at the Gibraltar site that the masonry dam can be gradually built higher as the demand of the city for a greater water supply grows, while there are distinct limitations to the construction of a higher dam at the Mono site.

FINANCIAL STATEMENT.

The financial results to be expected from the expenditure of the money necessary to build the work above referred to are not extensively considered, because it is not so much a question of whether these works can be constructed at a commercial profit as it is a question of how much it will cost to get an adequate water supply for the locality. It goes without saying that if the coast district is to continue to grow it must have water, and the only question is whether this can be obtained at reasonable cost.

The output from this system should be 1½ million gallons daily for 10,000 people. On page 25 it is shown that in order to meet the worst-known drought of nineteen months and deliver 150 gallons daily for 10,000 persons, plus the evaporation, a storage capacity of 3,518 acre-feet is required. This is on the assumption that all of the water must come from the reservoir and none can be obtained from the tunnels or streams on the south side of the range, a condition which the writer believes never will exist, but which he assumes for safety. At the Gibraltar site a dam 95 feet high will practically accomplish this at a cost for dam and tunnel of $372,702. Assuming an interest rate of 4½ per cent on this cost, we shall have an annual

fixed charge of $16,772. The works will all be permanent. Construction and maintenance charges should be very low, say $4,000 per annum. Operation should not be over $2,000. This gives a total annual charge of $22,772 for 547 million gallons, or a maximum of 4.1 cents per 1,000 gallons delivered at the intake of the domestic system. As the dam is increased in height the cost per unit of storage and the proportional charge for the tunnel will rapidly decrease with the resulting increased supply. With a dam 155 feet high on the above basis the cost per thousand gallons would be 1.1 cents. The long tunnel will undoubtedly also itself contribute a material supply to the city. Mr. Canfield, the president of the Santa Barbara Water Company, states as follows:

Water is now sold in Santa Barbara at the rate of about 16 cents per thousand gallons to the city for street-sprinkling purposes (at the rate of $35,000 per year for 1 second-foot), and to private consumers at from 20 cents to 25 cents per thousand gallons, which are moderate rates as compared with those realized in some other cities in this State, and it is believed that although the development of the business in the future may justify some reduction of rates, an average rate of 15 cents per thousand gallons at least can be calculated upon.

This is certainly a very reasonable charge for water in southern California. The lowest meter rate known in the State (that of the city of Los Angeles) is 9 cents per 1,000 gallons delivered to the consumer. Of course, there must be an intermediate charge for distribution system and administration which comes after the water is delivered to the mains.

Both Mr. Wright and Mr. Purslow considered the construction of these storage reservoirs as a profitable investment from a commercial standpoint. If the water was delivered free at sea level to the city, it would cost two-thirds as much for fuel alone (say 2.7 cents), with triple-expansion engines, to pump it to the city reservoir as it would to obtain it from this contemplated system of storage reservoirs. If interest, depreciation, and services are considered it would cost more to pump it.

There would undoubtedly also be a very considerable element of profit that might be derived from the water power available from the supply, since the elevation of the southern portal of the tunnel is approximately 1,200 feet and the elevation of the domestic reservoirs only 350 feet.

The result of the construction of the long tunnel probably will be the construction of the dam to the maximum height commensurate with the water supply of Santa Ynez River by the city, or by other parties who might make arrangements with the city for carrying water through this long tunnel. This should be a condition that the city would encourage.[a] The water not required by the

[a] Since writing the above the city has entered into a contract with the Santa Barbara Water Company to permit of such a use of the city tunnel by the company.

municipality would be used in developing and irrigating the beautiful coast plain near Montecito or in other adjoining localities. The improvement of this region would, of course, add to the prosperity of the county and city of Santa Barbara.

In this report estimates on right of way have not been included.

CONCLUSIONS.

In conclusion it may be stated—

(1) That the only extensive addition that can be made to the water supply of the Santa Barbara coastal plain is by the construction of a tunnel from Santa Ynez River to the coast side of the mountains and the building of an impounding reservoir for the holding of the winter flood waters of Santa Ynez River.

(2) That by far the most desirable point on Santa Ynez River for this construction is the Gibraltar reservoir site.

(3) That the water can be delivered at a reasonable cost for both irrigation and domestic use to Santa Barbara and vicinity from this site, and the construction is believed to be entirely justified and commercially feasible.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE LIGNITE OF NORTH DAKOTA

AND ITS RELATION TO IRRIGATION

BY

F. A. WILDER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., June 18, 1904.

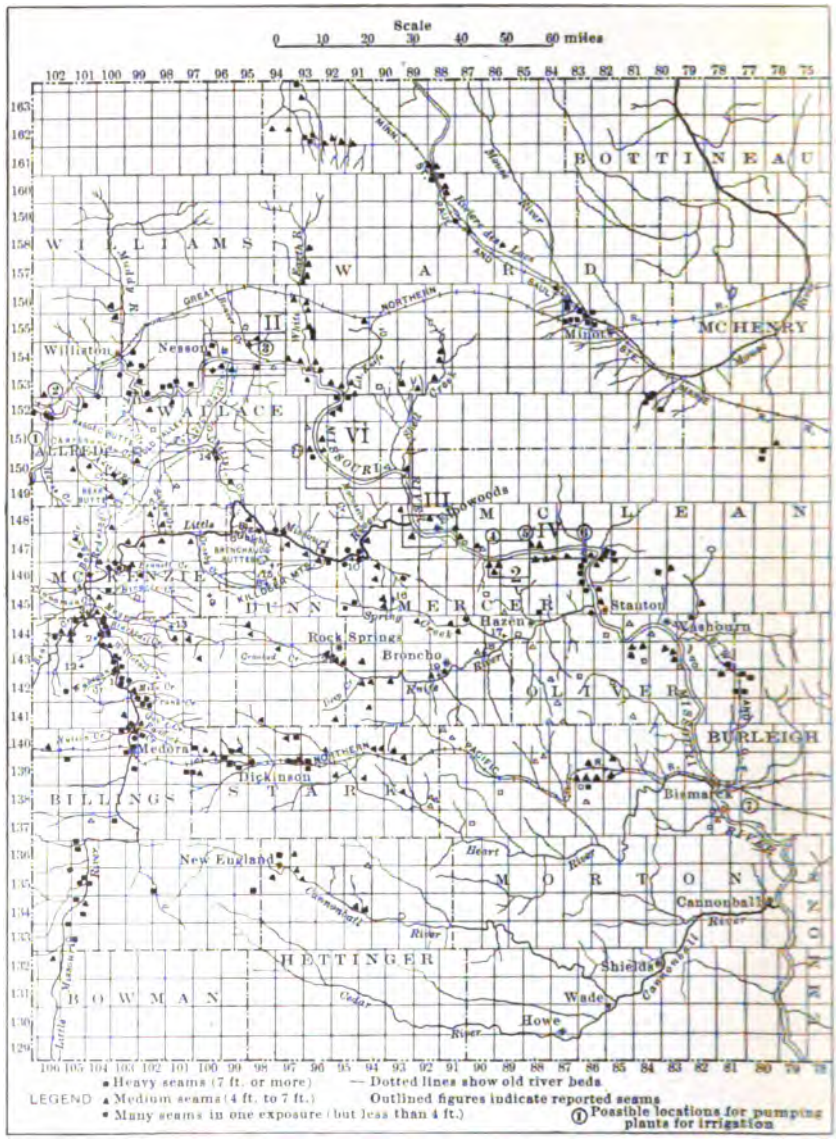
SIR: I have the honor to transmit herewith a report by Prof. F. A. Wilder on the lignite of North Dakota and its relation to irrigation, and recommend that it be published in the series of Water-Supply and Irrigation Papers.

The investigation on which this report was based was carried on under the charge of Mr. N. H. Darton as a part of the general investigation of the underground-water resources of the western portion of the United States. It is thought that the information contained in the paper will be of interest in connection with the underground-water resources of North Dakota.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.



MAP OF WESTERN PART OF NORTH DAKOTA.

THE LIGNITE OF NORTH DAKOTA AND ITS RELATION TO IRRIGATION.

By F. A. Wilder.

INTRODUCTION.

The areas most favorably situated for irrigation in North Dakota are the broad terraces along the Missouri and its tributaries. These streams are deeply intrenched, and it does not seem possible by means now available to raise water from them a vertical distance of from 150 to 400 feet over the bluffs that rather sharply bound the broad valleys.

When the Yellowstone enters the State it has a fall per mile of only 2.7 feet, while the Missouri's gradient for an equal distance is about 2 feet. A fall of 1 foot per mile is necessary to carry water in an irrigating ditch, so that to raise water 40 feet above the Missouri would require a ditch 40 miles long. The tributaries of the Missouri have gradients somewhat higher, but the flats along them are cut up by the meandering of the streams, and conditions are not favorable for long lateral ditches or extensive reservoirs.

On account of the fertile terraces in the valleys of the streams, ranging from 15 to 100 feet in elevation above water level, and the abundance of lignite along them, it seemed desirable to consider the possibility of irrigating the 250,000 acres included in the stream terraces by pumping from the rivers directly, using lignite as fuel. The lignite area, therefore, has been studied, and the nature of the lignite beds investigated. Practical tests have been made to determine the value of this material as fuel for generating steam, and computations have been made to ascertain, at least in a rough way, the cost of irrigating river flats which are less than 100 feet above the streams. The Missouri and its tributaries in North Dakota have been followed, and the extent and elevation of the river flats and the amount and quality of the lignite near them have been noted.

If only a small fraction of the western part of the State is under irrigation, the productiveness of the whole region will be greatly increased. Every river valley contains land which may be considered with reference to irrigation possibilities. With a few acres which can be watered at will, and abundant range for cattle in the broken

or rolling land back of the valley, ten families, by combining farming with cattle raising, will prosper where one finds a living now. These conditions will lay a sure foundation for the dairying industry, which should be one of the foremost of the State.

LIGNITE AREA IN NORTH DAKOTA.

While thin beds of lignite have been recognized in the eastern part of the State and have been previously described,[a] the only workable beds east of the center of the State are in the Turtle Mountains and at the southern bend of the Sheyenne River, about 25 miles southeast of Valley City, the Turtle Mountains being an outlier of the lignite area proper. The region in which lignite may reasonably be expected to be found, and which is discussed in this bulletin, may be roughly bounded on the east by a line beginning at the northern boundary of the State, 30 miles east of the Minneapolis, St. Paul and Sault Ste. Marie Railway, and extending southeast to Harvey, thence south through Steele to the southern boundary. More careful study, aided by well borings, which will doubtless be made as the country is settled, will perhaps shift this line at certain points 30 or 40 miles east or west. On the north, south, and west the lignite continues beyond the boundaries of the State. This region is of very great extent, having an area equal to half of that of the State of Ohio.

It is highly probable that lignite does not exist in beds of workable thickness in every part of this region, but it is equally probable that the fraction of the area lacking lignite in beds of three or more feet in thickness is a small one, not more than one-fifth of the whole. In the southeastern portion of the area, about the lower part of Cannonball River, thick beds seem to be lacking. Where heavy beds are present, all may not be available, either on account of depth or some difficulty in mining, and throughout the eastern portion of the region they are so thoroughly concealed by glacial drift that without a knowledge of the underlying formations and of the surrounding country their existence would be unsuspected.

The restriction of the term lignite area to the region in which workable beds of lignite are found greatly simplifies the stratigraphic series and limits this section to a consideration of the Laramie and the glacial drift.

The Laramie, which is the latest stage of the Cretaceous, contains all of the workable lignite in North Dakota. Early students of the field referred part of the lignite beds to the "Fort Union" on paleontologic grounds. Reasons for retaining the distinction have been

[a] Upham, Warren, The glacial Lake Agassiz: Mon. U. S. Geol. Survey, vol. 25, 1895, p. 92.

seemed adequate, and the effort may well be abandoned. The Laramie is found over the region previously outlined as the lignite area, though its eastern border is buried, often deeply, by glacial drift. The difference in elevation of its deposits actually exposed within the State is at least 1,400 feet. Its greatest thickness, shown with certainty by the well at Medora to be more than 2,000 feet, occurs in the western part of the State, while its vertical extent gradually decreases toward the east till at the edge of the Coteau du Missouri it drops off sharply, beyond which it continues as a relatively thin series. The Laramie consists of clays, sands, sandstone, lignite, and thin bands of hematite, clay ironstone, and shaly limestone.

OCCURRENCE OF THE LIGNITE.

The numerous natural exposures of lignite in the driftless area and the remarkably fine opportunity to study the Laramie strata given by the badlands make it possible to draw, even from a preliminary study of the region, rather far-reaching conclusions in regard to the nature of the lignite beds. Five well-developed beds outcrop in the bluffs of the Little Missouri at Medora and may be traced for miles both north and south of this point. Along the Missouri south of Williston five or six beds show in a single section and can be traced for long distances, while on the Fort Berthold Reservation nine well-developed beds occur in a single exposure. The wells at Medora and Dickinson, a record of which is given in fig. 1, show an even greater number of beds. Near the eastern edge of the lignite area the number of beds is greatly reduced, but even here two or three exist at certain points, though generally but one is workable.

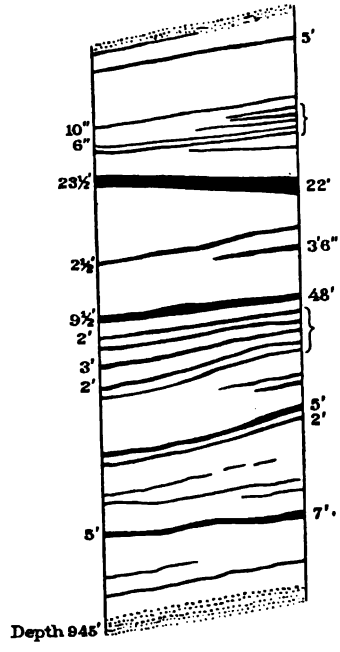


FIG. 1.—Diagram of lignite beds between Medora and Dickinson, N. Dak., by N. H. Darton.

On account of the nature of the beds, considered in a later paragraph, their number does not remain constant through large areas, and it is possible, though hardly probable, that at a few localities in the heart of the lignite area a prospect hole might pass completely through the Laramie, and not encounter a single lignite bed. This variation in number

and thickness of beds, often within comparatively short distances, will be a factor of great practical importance in opening up on a large scale a new lignite field. In the first place, it will increase the number of prospect holes that must be sunk to determine the amount of available coal in a given area. To offset this, however, are a number of conditions which make prospecting unusually easy.

Thickness of beds.—The lignite beds in North Dakota vary in thickness from an inch to 40 feet. This maximum thickness, which was carefully measured in the summer of 1902, occurs at an outcrop in sec. 31, T. 135, R. 101, which will be described in connection with the lignite on Little Missouri River. Three beds that reach a thickness of 25 feet are known, while beds 15 feet thick are not uncommon. In the western part of the State beds 2 and 3 feet thick are so common that in this report it is not practicable to note them minutely.

Extent of beds.—As important from an economic point of view as their thickness is the question of their persistence laterally. Attention was directed to this point, and the elevation of beds was noted in order to correlate, if possible, the beds exposed at one point with those at another. Generally such a correlation of beds distant from one another a number of miles was impossible on account of variations in thickness and elevation. While a single bed was often traced for 5 or 6 miles along the banks of the Little Missouri, another seen at the same time might thin out and give place to others above or below. The interrupted bed might begin again farther on after a break of half a mile or more, the lignite meanwhile being replaced by a bituminous or a nearly pure clay. The deduction, which early in the work seemed true, that certain horizons in the Laramie are much richer in lignite than others was not borne out by later observations. For a given locality the statement holds good, but a horizon which abounds in lignite at one point may be barren in another. A striking instance of the rapid thinning out of a bed is given by the 40-foot bed already referred to, which within one-fourth of a mile decreases to 17 feet, the top and bottom drawing together like the surfaces of a lense. Sufficient work has been done at one point near Minot to demonstrate the persistence of a thick bed beneath the greater part of a township, but this seems to be the exception rather than the rule. N. H. Darton has suggested a correlation of the beds encountered in the wells at Medora and Dickinson, but as the distance between these points is 39 miles, and lignite beds vary so greatly in order and continuity, the identity of the beds can not be established.

Variations in fuel value in a single bed.—A majority of the beds examined and tested show no great difference in fuel value from top to bottom. In some instances, however, the differences in the com-

position of the lignite in a given bed are considerable. Not infrequently the upper foot or two are inferior, and are left for roof in mining. The loss in this case is not as great as might be expected, for it is often more economical to leave coal for a roof than to timber. When the lignite lies directly under the glacial drift, as at the Hanchett mine, 10 miles southwest of Velva, the upper portion shows deterioration. Shaly layers sometimes occur, which if mixed with the coal from the rest of the bed raise the percentage of ash for the whole very considerably. Sulphur in any form is present commonly only in traces. Iron nodules, which prove so annoying to the operator of mining machines in the East, do not occur in the lignite, and there are no hindrances to the use of drills and undercutting machinery.

Variations in fuel value in different beds.—The chemical analyses of 70 samples from as many beds, given on pages 17 and 18, throw light on the fuel value of lignites from as many parts of the State. Samples were not taken from beds that were obviously too thin or too impure to be of economic value, but, on the other hand, all analyses made are given, whether favorable to the lignite or not. The lignites taken as a whole will probably average better than the samples analyzed indicate, for in many cases fresh material could not be obtained, and the weathering on the surface of a natural exposure is sufficient to lessen the carbon values for some feet from the surface. In the discussion which follows, lignites which are reported as good have between 40 and 50 per cent of fixed carbon and not more than 8 per cent of ash.

Possibilities of coal at greater depths.—There are no theoretical considerations to support the rather common notion that at greater depths a higher grade of coal exists. The analyses of the coals found by the railroads in the deep drillings in the western part of the State have not been examined, but as these borings were made some years ago and no development work has followed, the inference seems fair that bituminous coal in significant quantities was not found.

A popular fallacy in regard to lignite.—The belief so often expressed that lignite beds outcropping on slopes are certain to thicken is hard to account for. While in many cases the beds doubtless thicken away from the outcrop, the reverse will as often prove true. The lignite beds being in general lens-like, it is impossible without drilling to determine whether the outcrop represents a section near the edge of the lens or across the center. If the outcrop represents a section near the edge of the lens the lignite will thicken as the drift goes into the hill or bank till the center of the lens is reached, while if it is across the center the lignite will become thinner.

OUTPUT OF LIGNITE IN 1902.

Following is a summary of the output of the lignite of North Dakota mines in 1902:

Summary, by counties, of lignite output for 1902.

County.	Loaded at mine for shipment.	Sold to local trade.	Total product.	Total value.	Average spot value per ton.
	Short tons.	*Short tons.*	*Short tons.*		
Billings	.....	5,000	5,000	$4,000	$0.80
Burleigh	120,000	10,000	130,000	169,000	1.30
Emmons	.....	1,000	1,000	2,750	2.75
Mercer	.....	3,000	3,000	2,400	.80
Morton	30,000	5,000	35,000	45,000	1.30
McLean	.....	4,000	4,000	5,200	1.30
Oliver	.....	3,000	3,000	2,400	.80
Stark	45,000	10,000	55,000	66,000	1.20
Ward	57,800	19,000	76,800	107,520	1.40
Williams	.....	3,000	3,000	24,000	.80
Total	.....	.....	315,800	428,270	

FUEL VALUE OF NORTH DAKOTA LIGNITE.

The fuel value of a given lignite will vary considerably with the conditions under which, and the purpose for which, it is used. In one connection it may be esteemed highly and in another have no value at all. Out of this fact grows the diversity of opinion in regard to a number of well-known lignites of the State. A lignite whose value as a steam coal is very high may not prove suitable for certain kinds of stoves. An actual case will serve well for illustration. In two localities lignite from seams that are high in ash, due to admixture of clay, are highly valued for heating purposes, because the clay enables them to stand up well and prevents slacking. Judged by ordinary standards these lignites are very inferior. These recognized standards are: The amount of fixed carbon and the percentage of ash that the lignite contains, the result given by the calorimeter, and the amount of water that a given amount of lignite will evaporate. Of the three tests the last is the most satisfactory. The lignites have been tested in accordance with these, as well as in a variety of practical ways, and a brief statement of results is appended.

LABORATORY TESTS.

CHEMICAL PROPERTIES OF LIGNITE.

Fixed carbon.—The average amount of fixed carbon in 26 samples of North Dakota lignite analyzed in 1900, when thoroughly dried, was 52 per cent. Sixty samples, after thorough drying, gave 51.21 per cent of fixed carbon. Compilations of analyses of 41 samples of West Virginia bituminous coal show 67.16 per cent of fixed carbon; 22 samples of the better grades of semibituminous dry coals of Maryland show 75.99 per cent; and 26 samples of dry bituminous coal from Pennsylvania show 67.97 per cent. Judged by the fixed carbon alone the heating power of North Dakota lignite is 76 per cent of that of West Virginia bituminous, 65.9 per cent of that of Maryland semibituminous, and 74.4 per cent of that of Pennsylvania bituminous. These figures show that the North Dakota lignites rank far above the coals that are the average representatives of this class.

With respect to fixed carbon, the lignite of North Dakota appears to be equal to the product of the Western Interior coal field (which includes Iowa, Missouri, and Kansas). According to a recent United States Geological Survey report,[a] the amount of fixed carbon in 12 samples from the Western Interior field, computed on a dry basis, averages about 50 per cent. These coals, however, have a somewhat higher evaporative power than the lignites.

Volatile matter.—The average amount of volatile matter, exclusive of water, computed from 60 analyses of different lignite coals, is 35.63 per cent. When the fixed carbon alone is considered as determining the fuel value of a coal the worth of the volatile matter is overlooked. Under proper conditions these gases may be made to develop a great deal of heat, and no appliances which aim at an economical combustion of lignite can afford to disregard them.

Ash.—The percentage of ash in the 60 samples is generally low, the average amounting to 8.5 per cent. By deducting 4 inferior samples, the average will be lowered to 7.5 per cent. Compared with coals of the Iowa, Missouri, and Kansas region, lignites are notably purer. In the ash from some North Dakota coals there is a tendency to form clinkers, due to the presence of clay, but generally the lignite burns like wood, leaving a gray powdery residue.

Sulphur.—The percentage of sulphur in the lignites is usually

[a] Bain, H. Foster, Western Interior coal field: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 333-366.

low—much lower than in most bituminous coals. The following samples are fairly representative:

Percentage of sulphur in North Dakota lignites.

	Per cent
Lehigh mine	0.88
Washburn mine	.91
Forty-foot vein, Billings County	1.10
Electric mine, Kenmare	.68
Davis mine (Mouse River Lignite Company)	.35

The sulphur in these analyses was determined in dry coal, which brings the percentage one-fourth higher than for lignite fresh from the mine. A yellow powder composed of calcium sulphate and iron oxide often occurs in the upper part of lignite seams and in color and texture resembles sulphur.

The average of 60 tests shows that the lignite contains 35.66 per cent of volatile matter and about 30 per cent of moisture. Several service tests of lignite show it to have an evaporative power of 4.2 pounds of water from and at 212° F. per pound of fuel. This amount is below the average test, but it is the amount used in computations for fuel value, and is 75 per cent of that of Iowa coal and 70 per cent of that of the Missouri product.

PHYSICAL PROPERTIES OF LIGNITE.

Moisture.—In a far larger measure than is the case with bituminous coal, the physical properties of lignite must be kept in mind in considering its fuel value. A series of analyses subsequently quoted shows that lignite fresh from the mine contains 30 per cent of moisture, in which respect samples taken from various parts of the State differ but slightly. When shipped under ordinary conditions and in the usual manner, the lignite reaches the engine room with nearly all of its moisture. Small samples that are more or less exposed to the air for two months reach the laboratory with from 10 to 20 per cent of moisture, as shown by the following tables, which give analyses of specimens in which no special effort was made to prevent drying.

The expense of shipping this moisture and its effect on the heating properties of the lignite are points worthy of careful study and experiment. The general opinion of those burning lignite is that if the lignite, in drying, did not fall to pieces, becoming so fine that it was apt to go through the grates, there would be great economy in burning it after drying, and that in those devices where powdered or fine coal is used the dry lignite presents a material saving over the "green." Theoretically, it would seem that this should be the case, for the heat necessary to volatilize the 30 per cent of moisture would be saved, and there is no apparent reason for a material loss of the volatile gases in drying.

In any case, if the coal could be dried before shipping and economically burned after drying, the freight charges would be reduced nearly one-third.

The so-called slacking of lignite is the process of crumbling that it undergoes when drying. It probably loses none of its fuel value in consequence, and there is probably a gain in this respect due to the absence of the moisture. Special conditions are necessary, however, to burn this fine coal advantageously, the danger being that it will fall through the grate or be blown out through the stack.

ANALYSES OF SAMPLES OF LIGNITE.

Analyses of lignite fresh from mine.

[Fixed carbon, volatile matter, and ash computed on dry basis.]

Mine and location.	Fixed carbon.	Volatile matter.	Ash.	Moisture.
Mouse River Lignite Co., Burlington:				
4 feet from bottom	51.28	35.83	11.89	32.00
Top	46.42	32.60	20.98	30.00
16 inches above clay seam	47.36	42.14	10.50	29.40
Lower 20 inches	52.96	38.93	8.11	34.70
Electric mine, Kenmare:				
4 feet from floor	57.95	34.41	7.64	32.90
3 feet from floor	59.19	36.56	4.25	35.00
Bottom	56.58	34.44	6.98	34.80
Top	56.87	36.58	6.55	34.80
Diamond mine, Kenmare:				
Top	52.98	37.24	9.78	33.00
Center	56.82	33.77	9.41	33.00
Lower 18 inches	56.97	36.28	6.75	33.60
Dakota Lignite and Brick Co., near Burlington	55.61	40.08	4.30	23.40
New Era mine, near Minot	57.66	38.22	4.12	33.60
Smith-Kenmare Dry Coal Co.:				
Next to clay	55.55	36.79	7.67	33.20
Next to roof	52.30	39.90	7.80	32.00
1 foot below roof	55.25	33.50	11.25	32.60
Wadeson mine, Sims	50.47	39.21	10.32	30.29
Lehigh mine	51.62	43.18	5.21	34.30
Satterlund mine, near Washburn	55.89	37.50	6.61	30.91
Washburn mine, at Wilton	54.93	38.75	6.32	31.82
Dickinson Brick Co	46.89	38.23	14.88	27.82
On Heart River, near Dickinson	60.49	38.31	1.20	14.25
Consolidated Coal Co., New Salem	53.86	41.66	4.48	27.48

Analyses of lignite partly dried.

[Fixed carbon, volatile matter, and ash computed on dry basis.]

Mine and location.	Fixed carbon.	Volatile matter.	Ash.	Moisture.
Sample from Beaver Creek, E. Williams County	57.97	38.34	3.69	18.13
Sample from Dry Fork Creek	48.99	35.81	15.19	16.26
Outcrops near agency at Elbowoods	57.29	37.29	4.76	19.97
Ed Hall's mine, near Fort Berthold Agency	51.41	35.16	13.43	17.63
Anderson mine, Stanley	50.95	38.40	16.65	20.36
Jones mine, 16 miles southwest of Balfour	53.77	37.72	8.51	21.7[illegible]
Missouri River, west of White Earth River	51.60	43.04	5.36	13.3[illegible]
Rose Hill mine, 15 miles southwest of Balfour	53.11	38.81	8.08	18.0[illegible]
Opening, 8 miles north of White Earth	56.51	36.94	6.55	17.76
F. F. Alger mine, Stanley, Ward County	49.63	35.57	14.80	16.[illegible]
Pleasant Valley mine, Shell Creek	55.09	39.89	5.02	17.[illegible]
Sikes mine on the Little Knife	47.55	42.68	9.77	16.[illegible]
Badlands, 6 miles east of Fort Berthold	47.38	42.75	9.87	14.64
Boyds mine, sec. 17, T. 152, R. 94	55.18	37.85	6.97	17.6[illegible]
Nesson opening	60.38	36.09	3.53	19.9[illegible]
Williams opening, 5 miles south of White Earth	44.49	31.59	23.92	17.[illegible]
Gille-Miller mine	60.12	34.19	5.69	18.[illegible]
Sorenson mine, sec. 32, T. 162, R. 92	60.95	34.12	4.93	19.4[illegible]
Pony Gulch mine, 16 miles southwest of Harvey	51.66	36.72	11.62	19.[illegible]
Leigh Ericson, Donnybrook	59.75	35.14	5.11	19.[illegible]
Lloyd Mining Co	58.23	33.13	8.64	17.[illegible]
Scribner's mine	56.61	36.87	12.52	16.[illegible]
Drift, near railroad bridge near Burlington	56.57	38.01	5.42	17.[illegible]
Turtle Gulch mine, sec. 14, T. 152, R. 81	53.78	37.20	9.02	20.0[illegible]
Wm. Lacy's land, Coal Harbor	53.43	39.14	7.43	18.[illegible]
Hanchett mine, southwest of Velva	53.60	40.14	6.16	16.6[illegible]
Coal Canyon, 30 miles south of Medora	52.47	38.57	8.96	16.7[illegible]
J. C. Gamel's ranch, sec. 20, T. 133, R. 104	55.90	37.59	6.51	18.24
Sentinel Butte, Billings County	48.04	42.67	9.29	18.9[illegible]
From 777 ranch on Little Missouri	43.47	34.55	21.98	14.[illegible]
Forty-foot seam, sec. 31, T. 135, R. 101	51.79	38.69	9.52	13.[illegible]
Lower vein on Missouri River, 3 miles south of Williston	50.65	36.15	13.20	10.[illegible]
Twelve-foot seam, 3 miles east of Williston	54.38	36.37	9.15	11.[illegible]
Heaton's land, sec. 29, T. 145, R. 80	54.59	39.49	5.92	11.[illegible]
Coal Lake mine, sec. 22, T. 146, R. 82	55.73	38.74	5.53	11.[illegible]
Reiss mine, New England	53.03	38.39	8.58	24.[illegible]
Stone-Bird mine, near Belfield	56.61	35.71	7.68	21.[illegible]
Average	51.21	35.63	8.50	...

Number of samples in Tables I and II, 60.

Deductions.—The method of analysis employed differs from that commonly used for lignites, for the percentage of moisture is first computed and then, after the moisture has been expelled, the amount of the other constituents is determined. The percentage of fixed carbon, volatile matter, and ash is made somewhat higher than when the undried coal is analyzed. The practical difficulty in bringing the lignite to the laboratory without partly drying, however, makes it much more desirable to compute composition on a dry basis.

Even when allowance is made for this method of computation the percentage of fixed carbon is high enough, if this alone is considered, to remove these coals from the lignites and place them with the semi-bituminous or steam coals. The content of water, however, about 30 per cent, keeps them in the former class.

PRACTICAL USE.

EVAPORATIVE TESTS.

More satisfactory than either chemical or calorimetric tests are practical evaporative tests carried on with boilers of standard patterns. A number of such tests have been made, and in some cases eastern coal also has been tested in the same boilers and under practically the same conditions, so that, knowing the price of each coal at the point given, it is possible to determine definitely the economy resulting from use of lignite.

Tests under natural draft.—The following test was made at the asylum for the insane at Jamestown by Chief Engineer Thomas Pettigrew, whose careful study of proper methods for burning lignite has greatly advanced the lignite industry.

Test of lignite at insane asylum at Jamestown, N. Dak.

[Date of test: Youghiogheny coal, August 6, 1894; lignite coal, August 8, 1894.]

	Youghiogheny coal.	Lignite coal.
Duration of test ..... hours	7½	8
Average temperature of feed water ..... ° F	74	74
Coal burned ..... pounds	1,400	3,370
Combustible ..... do	1,243	3,170
Ash ..... per cent	11.21	5.93
Coal burned per square foot of grate per hour ..... pounds	8.29	18.72
Total water evaporated at temperature of feed ..... do	8,837	14,157
Water evaporated in pounds per pound of coal actual condition	6.312	4.2
Water evaporated per pound of combustible ..... pounds	7.1	4.46
Temperature of flue gases ..... ° F	510	510
Boiler 6 feet in diameter by 16 feet long, with 80 4½-inch flues; grate surface, 4 feet 5 inches by 5 feet; coal 3 days from mine; value of coal	$1.00	$0.665

The cost of Youghiogheny lump at Jamestown was $6.80 per ton and of lignite $2.80.

Test of Lehigh lignite made by the Missouri Valley Milling Company at Mandan, N. Dak.

Duration of test	hours	11
Kind of furnace		Smith-White
Grate surface	square feet	9
Width of air space in grate	inch	[illegible]
Water-heating surface	square feet	1,549
Ratio of water-heating surface to grate surface		51 to 1
Average steam pressure		104
Average temperature of feed water entering boiler	° F	175
Total coal fed to furnace	pounds	12,221
Moisture in coal	per cent	23
Coal consumed per square foot of grate per hour	pounds	37
Cost of coal delivered at mill per ton		$1.60
Total cost of coal		$9.77
Total weight of water fed to boiler	pounds	56,350
Water evaporated per hour from and at 212° F	do	5,554
Horsepower developed		163
Cost of fuel for evaporating 1,000 pounds of water		$0.1734
Average horsepower of engine		190
Cost per horsepower per hour		$0.0047

The mill has a capacity of 450 barrels of flour per day, and the cost of fuel, when lignite is burned, per barrel of flour ground is 4.46 cents.

Test of Wilton lignite coal in the Fargo-Edison Company's plant at Fargo, N. Dak., January 9, 1901.

Duration of test	hours	12
Boilers used: Two 16 feet by 72 inches tubular, one 200-horsepower Heine water tube.		
Total heating surface	square feet	4,823
Total grate surface	do	88
Average steam pressure	pounds	83
Average temperature of feed water	°F	140
Total weight of coal fired	pounds	26,400
Cost of coal per ton of 2,000 pounds at boilers		$2.60
Total cost of coal		$34.32
Total weight of water pumped into boilers and apparently evaporated	pounds	97,700
Water evaporated per pound of coal from average pressure and temperature	pounds	3.7
Equivalent evaporation from and at 212° F	do	4.1
Coal burned per square foot of grate per hour	do	25
Cost of fuel to evaporate 1,000 pounds of water		$0.352
Moisture in coal	per cent	30
Refuse in coal	do	34

Boiler test of lignite at North Dakota Agricultural College, March 8, 1902.

Duration of test	hours	8.5
Average atmospheric pressure	inches	28.5
Gage pressure	pounds	73.8
Temperature of feed water	°F	144
Kind of fuel		"White ash" lignite.
Moisture in coal	per cent	36
Description of boiler: Common fire tubular boiler, with 62 flues, 3 inches in diameter, 16 feet long; diameter of shell, 60 inches.		
Water-heating surface	square feet	962
Ratio of water-heating surface to grate surface		.025
Coal burned	pounds	3,907
Unburned fuel		None.
Average coal burned in fifteen minutes	pounds	144.91
Total refuse from coal	do	168
Total combustible	do	2,314.5
Average combustible for fifteen minutes	do	68.05
Quality of steam (saturated steam taken as unity)	per cent	0.97
Total water pumped into the boiler	pounds	1,236.5
Water apparently evaporated per pound of fuel burned		3.16
Water actually evaporated, corrected from moisture	pounds	11,994
Equivalent water evaporated into dry steam from and at 212° F.	do	13,228
Equivalent evaporation into dry steam from and at 212° F. per pound of dry coal burned	pounds	3.385
Coal burned per square foot of grate surface per hour	do	18.38
Water evaporated from and at 212° F. per square foot of heating surface	pounds	1.606
Equivalent evaporation into dry steam per pound of combustible		5.68
Average ash	per cent	9.03
Combustible	do	90.97
Gas analysis:		
CO_2	do	7
O	do	6
CO	do	1.05

Test conducted by Lewis Larson.

In the foregoing tests natural draft only was used.

Test under forced draft.—On November 17, 1902, a preliminary test of lignite coal from the mine of the Kenmare Coal Company was made under boilers No. 1 and No. 3 of the State University heating plant. During the winter of 1904 more elaborate tests were made under boilers provided with lignite fire-brick arches and under boilers without arches, which it is hoped will settle the disputed question as to the real worth of these arches. For the test given below a steam calorimeter was not available, and the water fed to the boiler is assumed to have been evaporated. The boilers are fire tubular; diameter of shell, 54 inches. Each contains forty-eight 16-foot flues, with inside diameter of 3½ inches, and each contains 841.76 square feet of heating surface. They are provided with the

lignite fire-brick arches, and the test was made under forced draft from a fan.

Test of lignite at State University.

Duration of test	hours	12½
Percentage of moisture as shown by four days' drying	per cent	10
Percentage of ash	do	7.828
Evaporated per pound of fuel from and at 212° F.	pounds	4.367
Evaporated per pound combustible (coal minus ash and water) from and at 212° F.	pounds	5.242

With boiler and grate conditions about like those used in the test at the asylum for the insane, already quoted, three Iowa coals tested at Des Moines gave per pound of coal a water evaporation from and at 212° F. of 5.44, 5.21, and 6.52 pounds, respectively. Four standard Missouri coals gave 6.84, 6.27, 6.23, and 5.86 pounds, respectively. Comparing the results obtained from lignite with these—taking the evaporative powers of lignite at 4.2 pounds, which is conservative—the lignite appears to be worth 75 per cent of the Iowa coal and 70 per cent of the Missouri.

METHODS OF BURNING.

Automatic stokers.—In plants where considerable quantities of lignite are used automatic stokers with forced drafts give most satisfactory results. At the Fargo-Edison electric plant at Fargo stokers which burn the refuse from the Washburn mine, which consists of the cuttings of the mining machines and the fine coal incidental to blasting, are in successful operation and demonstrate clearly the ability of lignite to compete with eastern coal in the Red River Valley. The lignite, varying in size from dust to fragments of half a pound weight, is shoveled into hoppers and fed into the furnace by a screw 8 or 9 inches in diameter, the flanges being 6 inches apart. Forced draft is introduced into the ash pit. The cost of firing is greatly reduced and the fires are exceedingly uniform. Other forms of stokers are doubtless practical.

When an economic method of drying the lignite before shipping from the mine is found it will be possible to save 30 per cent of the freight. With automatis stokers, the reduction of the lignite to fragments in the process of drying will be advantageous.

Forced draft and arches.—On account of the gases, volatile at a moderate temperature, that lignite contains, special devices have been introduced in furnaces intended for its consumption, by which these gases shall be promptly raised to the temperature necessary to secure their complete combustion. For this purpose there is often built over the front of the fire box an arch of fire brick, which, becoming intensely hot, secures the combustion of the gases that come

in contact with it. That it is useful for this purpose there can be no question. The question remains as to whether it adds to the efficiency of the coal, since it shuts off a portion of the boiler from direct contact with the fire and interferes with firing, when fuel is fed with a shovel. To a certain extent the bricks themselves conduct heat to the boiler. The value of these arches is not fully demonstrated and the cost of their installation is considerable.

Forced draft is convenient if the plant is large, but lignite is giving excellent results in a number of plants where natural draft only is used. With forced draft a short stack is sufficient, and this saving over the construction of a tall chimney is often enough to pay for the installation of the fan. The forced draft is introduced into the center of the ash pit and there caused to spread out, so that it reaches all parts of the grate uniformly. Induced draft is not recommended for any purpose in connection with lignite, though a combination of forced and induced drafts seems to solve satisfactorily certain difficulties in burning brick.

Natural draft.—Very satisfactory results are being obtained with lignite and natural draft at the Minot electric-light plant, the Kenmare roller mill, and similar institutions throughout the State. With natural draft a large boiler and grate surface are desirable, though not absolutely essential, and more experience in firing lignite is necessary. The fires should not be allowed to fall off, for if green lignite is thrown into the furnace when the steam is falling, it acts like a blanket, and temporarily smothers the fire. Fuel should be added when the fire is high and by the time the steam gage begins to drop the fresh lignite has been dried and is ready to burn. It is a good plan to fire but one side of the furnace at a time.

Commercial use.—Two large flouring mills, at Mandan and Jamestown, use lignite exclusively for fuel. The plant of the Russell-Miller Milling Company, at Jamestown, a 500-barrel mill, uses a single boiler, 72 inches by 16 feet, with seventy-two 4-inch flues. Shaking grates, giving an area of 36 square feet with ½-inch air spaces, are used. Forced draft secured by a fan is employed, and 170 horsepower is maintained for twelve hours with the use of 7,600 pounds of Washburn lignite. The engine is a Corliss compound condensing, rated at only 165 horsepower. A careful test has shown that 3.73 pounds of Wilton lignite will maintain 1 horsepower per hour. With lignite at $2.45 at the mill, the cost of fuel per barrel of flour is 4.5 cents.

The Hebron roller mill burns 4 tons of lignite in twenty-four hours, with an output of 100 barrels of flour, besides custom work. Natural draft and ordinary grates are used.

The Kenmare roller mill, using a boiler 66 inches in diameter and 16 feet long, and grate with ⅜-inch openings, uses 161 pounds of slack lignite per hour to generate 40 horsepower, the steam pressure being 65 pounds.

The Washburn roller mill maintains 30 horsepower for twelve hours with 1½ tons of lignite. The boiler is 12 feet by 36 inches, and the engine small and crowded.

The New Salem Roller Mill Company is operating a 125-barrel mill to its full capacity. The boiler is 14 feet by 52 inches, and the engine is rated at 75 horsepower. Forced draft is employed. In twelve hours 3,700 pounds of lignite are burned.

The electric plant at Dickinson burns lignite under a boiler 72 inches in diameter and 17 feet long, using ordinary grates and forced draft, the fan being driven by a 2-horsepower motor.

The Minot Electric Light Company employs 2 boilers 16 feet long and 54 inches in diameter. Fifty horsepower is maintained for ten hours with 2 tons of green lignite. Natural draft is used, and the engineer does the firing also.

PUMPING WATER WITH LIGNITE.

By Charles S. Magowan.

The computations on page 26 indicate the amount of lignite that will be required to raise water to the level of the various flats found on the streams in western North Dakota.

DUTY OF WATER.

The first question that presents itself is that of the duty of water. In the absence of definite data on this point from North Dakota it is necessary to rely on the results of irrigators who have worked under somewhat similar conditions. Wilson[a] records that in Montana a second-foot serves about 80 acres, and that from 15 to 18 inches in depth during an irrigating season is believed to be sufficient. Mr. Wilson makes the general statement that 1,000 gallons per minute will irrigate from 5 to 10 acres per day, and in the course of a season about 100 acres. If water is supplied to a 10-acre tract at the rate of 1,000 gallons per minute for twenty-four hours, the depth of the water over the whole tract will be 5.58 inches. If water to this depth applied five times during the irrigating season is sufficient, a plant of this capactiy should care for 200 acres. This statement is made because it is desired to use 1,000 gallons per minute and multiples thereof in discussing pump efficiencies.

[a] Manual of Irrigation and Engineering, 1903, pp. 55, 56.

CENTRIFUGAL PUMPS.

Centrifugal pumps only are discussed, since it is believed that in view of recent improvements that have been made in their construction no other pump can so economically handle large quantities of water under the given conditions, even for the higher lifts. The discussion is based on belt-driven centrifugal pumps, though some reference will be made to steam centrifugal pumping engines—that is, to machines where engine and pump are directly connected, being built on the same base.

The fuel that will be used in the locality under consideration is lignite that in service tests has been proved to have an evaporative power of 4.2 pounds of water from and at 212° F. per pound of fuel. This value will be used in the computations.

It is contemplated that engines will be used which will deliver at least 1 horsepower for every 35 pounds of steam furnished. This is a low-engine efficiency, and should be realized even under extremely adverse circumstances. By using engines of higher grade—and these should be employed with the larger pumps, where compound, condensing, triple-expansion, or even quadruple-expansion engines might be economically used—the efficiency would be more than doubled, the fuel consumption being correspondingly reduced.

EFFICIENCY OF PUMPS.

The accompanying table shows the capacities and efficiencies of centrifugal pumps of several sizes, all belt driven, together with the amounts of lignite that will probably be required to lift the water to various heights.

The per cent of pump efficiency noted in the table is obtained by comparing the amount of work realized with the amount of power applied to the shaft of the pump, and it is well to note that the efficiency increases as the capacity of the pump increases, thus favoring the installation of large plants.

The prices quoted are those furnished by manufacturers' agents, and are usually f. o. b. at Chicago or an eastern factory. A considerable range in price is noted, the difference being due to differences in weight, construction, and finish.

A new form of centrifugal pump known as the "Volute" is being placed upon the market at the present time, for which claims of increased efficiency are made, the claim being based on the increased care in the manufacture of the wheel and especially in the fitting of the runner, thus lessening the loss from "slip" otherwise sustained.

Capacities, efficiencies, and cost of centrifugal pumps, and amounts of lignite required to lift water to specified heights.

Number of pump (diameter in inches of discharge opening).	Capacity in gallons per minute.	Horsepower delivered to shaft of pump necessary to effect economical discharge at elevations of—				Efficiency of pump (per cent).	Tons[a] of lignite required to furnish power to operate engine and pump 24 hours when lifting the economical discharge to an elevation of—				Price of pump (approximate) f. o. b.
		20 feet.	40 feet.	60 feet.	80 feet.		20 feet.	40 feet.	60 feet.	80 feet.	
6	1,050	11.8	23.6	35.4	47.2	45	1.2	2.4	3.5	4.7	$120-$250
8	2,000	22.0	44.0	66.0	88.0	46	2.2	4.4	6.6	8.8	190-360
10	3,000	32.0	64.0	96.0	128.0	47	3.2	6.4	9.6	12.8	240-570
15	7,000	70.0	140.0	210.0	280.0	51	7.0	14.0	21.0	28.0	400-890
18	10,000	100.0	200.0	300.0	400.0	52	10.0	20.0	30.0	40.0	700-900
20	12,000	120.0	240.0	360.0	480.0	53	12.0	24.0	36.0	48.0	900
24	15,000	130.0	260.0	390.0	520.0	58	13.0	26.0	39.0	52.0	[b]1,700
36	32,000	260.0	520.0	780.0	1,040.0	62	26.0	52.0	78.0	104.0	

[a] Price of coal in this region varies from 50 cents to $2 per ton.
[b] Volute.

With the assumptions made above the computations for the fuel consumption become so simple that the tabulation of them seems almost unnecessary. For example, consider a No. 15 pump delivering 7,000 gallons of water per minute against a head of 60 feet. From the table the number of horsepower required is 210, this multiplied by 35, the steam consumption per horsepower per hour, and this by 24, the number of hours considered, and the product divided by 4.2 times 2,000, the result is the number of tons of lignite consumed. In the above case the computation is as follows: $210 \times \frac{35 \times 24}{4.2 \times 2{,}000} = 210 \times \frac{1}{10} = 21.0$. Thus, in any case, the number of tons of lignite that must be supplied to the furnace equals one-tenth of the number of horsepower that is required to operate the pump.

It will be noted that the sizes considered are those that give capacities of about 1,000 gallons per minute or multiples thereof. It is also well to note that the capacity of any of these pumps can be very materially increased by slightly increasing the number of revolutions, but the efficiency will thereby be diminished.

Engines for operating centrifugal pumps must be capable of running at high speed, especially if the pump is operated against a high head. For example, a No. 6 pump operating against an 80-foot head must make 857 revolutions per minute; a No. 24 pump operating against a 20-foot head must make 190 revolutions per minute, and the engine, if directly connected, must work at the same rate. Builders of centrifugal pumps also build engines to meet these requirements and connect them directly to the pumps, especially for the lower lifts.

A No. 6 centrifugal pump capable of working against a 30-foot head can be bought for $520 or less, while a No. 8 pump that will work against the same head will cost $690. One firm quotes a price of $500 on a 30-horse-power, automatic, high-speed engine, and $1,675 on a 200-horsepower engine. These prices are for engines only. The companies will furnish on request prices on the larger sizes of steam centrifugal pumps.

Some large plants of this kind have been installed and are reported as working successfully. At Albany, N. Y., two 18-inch pumps operated by direct-connected, vertical, cross-compound engines lift 10,000 gallons each per minute, with a reported efficiency of pump and engine of 66.3 per cent, and with a net efficiency of the pump alone of 77 per cent, the lift being 21 feet.

RIVER FLATS AND LIGNITE.

MISSOURI RIVER.

YELLOWSTONE FLATS.

Area and soil.—On entering North Dakota the course of the Yellowstone is toward the northwest, then north, and just before uniting with the Missouri somewhat south of west, its total course in the State amounting to about 15 miles. For this distance it keeps close to the bluffs at the right bank of the valley, leaving broad benches unbroken by meanders on the left. Above the flood plain, which is covered with a dense growth of willows, is a wooded bench from 10 to 15 feet above high water, where large cottonwoods flourish. Its extent may equal 4,000 or 5,000 acres. Ten feet above this and 20 feet above the river at high water is the edge of a beautiful and extensive grassed terrace, which rises gradually for 2 miles to the foot of the bluffs, and which has an area of about 15,000 acres, below a contour line drawn 80 feet above the river. It is not cut up by ravines or gullies and a trench can be carried along the 80-foot contour with but few flumes. With such an initial head, water can be taken to almost any point on the flat.

The soil is a good loam and the upper terrace is already well grassed, though at present it yields hay regularly only where naturally irrigated by water that comes down in Fourmile and Eightmile creeks and other coulees and spreads out over its surface. Much of the woodland lies high enough above the river to be free from ordinary river floods, and is inundated only at rare intervals by the gorging of the ice. In all, at least 15,000 acres on the left bank of the Yellowstone in North Dakota may be regarded as suitable for irrigation if water from the river can be raised 80 feet.

The area in North Dakota is but part of flats that extend into Montana as far as Terry. The fall of the Yellowstone is but 2.7 feet per mile, and a slope of 1 foot per mile would probably be needed in a lateral ditch. A very long lateral would be necessary to take water from the Yellowstone and cover the flats if gravity alone is relied on.

Lignite.—Heavy beds of lignite occur near Sidney, Mont., on the Yellowstone River, 15 miles west of the North Dakota line. On the creeks which empty into the Yellowstone from the south, and notably on Charbonneau Creek, heavy beds of lignite are said to outcrop.

BUFORD-TRENTON FLAT.

Area and soil.—Extending along the north side of the Missouri from the State line to the eastern edge of old Fort Buford Reservation, a distance of 16 miles, is an extensive flat which needs only water to become highly productive. At Trenton station, in the middle of this tract, the river swings in abruptly till it is close to the bluff, narrowing the flat for one-half mile. Enough remains, however, to provide space for a waterway or a pumping plant, so that if water were available and irrigation seemed desirable the level bench both east and west of Trenton could be irrigated from a single station.

The flat includes about 12,000 acres, divided between an upper grassed terrace and a lower wooded bench, the former having about twice the area of the latter. The wooded bench is from 20 to 25 feet above ordinary high water and is said to have been flooded but twice in twenty-eight years, the last time in the spring of 1891. In places it is being cleared and cultivated. Although some portions are sandy, it has for the most part a good soil. The second or grassed terrace rises gradually from the edge of the wooded terrace, where it is about 30 feet above high water, to the bluffs, at the base of which it is 80 feet above the river. It has a strong gumbo soil which grows bluejoint or wheat grass, cactus, and sage when unirrigated, while with irrigation it produces both grass and grain abundantly, yielding 2½ tons of excellent hay to the acre. The Great Northern Railway crosses it, running at the foot of the bluffs, giving ready access to market for produce raised on it.

The efforts now being made by Mr. Edwin Jack and others to irrigate parts of this area are described on pages 50 and 51. It will be possible to irrigate a part of it as they are doing by building reservoirs and diversion dams in the draws that cut the bluffs behind the flat, but for a large part of it the economy of this method may fairly be doubted. For the area as a whole it will be advisable to consider the possibility of raising water from Missouri River.

Lignite.—Only limited quantities of lignite are known in the bluffs just back of this tract, though large beds may sometime be discovered. Two miles from Buford, in sec. 31, T. 153, R. 103, a 4-foot bed of good lignite is mined to some extent by stripping. About 75 tons were taken out in the winter of 1902.

On Eightmile Creek, above Jack's ranch, a 3½-foot seam furnishes some lignite, while fuel from Buford is in part brought from the Yellowstone and in part from the seams in Glass Bluffs, across the river. If a pumping station were established at Trenton, where the river cuts back nearly to the bluffs and divides the tract into two parts, it might be practicable to ship coal from the mines already opened near Williston, a distance of only 25 miles. In this case good lignite, f. o. b. at Trenton, will cost $2.50 per ton. The lift at this point, to cover the entire tract of 12,000 acres, will be about 70 feet, though a large part of it could be watered with a lift considerably less.

MUDDY AND MISSOURI RIVER FLATS AT WILLISTON.

Area and soil.—The Muddy is the main tributary of the Missouri from the east and north in North Dakota. Its drainage area includes nearly one-half of Williams County, or 700 square miles. In addition to a water supply from direct rainfall, it is fed by a number of perennial springs. On June 27, 1903, it had a flow of 18 second-feet, an amount said to be normal for that season of the year. Its valley is broad and, in the main, fertile. The bottom lands are often a mile wide, while a strip half a mile wide fit for irrigation may be counted on for 20 miles or more from its mouth. There may be 10,000 acres along the stream that could be irrigated if water can be found for so large an area. Along its tributaries there is much land not included in the above estimate, portions of which are already irrigated, mainly by diversion dams for spring flooding.

To be taken with the Muddy River flats are 3,000 or 4,000 acres on the Missouri between Williston and the mouth of the Muddy. It is probable that the amount of water that the Muddy annually contributes to the Missouri is more than adequate to water the 15,000 acres that lie near it, but it has not been demonstrated that a large reservoir can be economically located on the stream. Its valley for 15 miles is broad and seems to offer no point where a short wall can retain a considerable amount of water. If a dam were erected above this point, the water from some of the principal tributaries which empty below would be lost. The Fred Rounsaville dam, which was intended for a diversion dam rather than for a reservoir, is described on page 51.

Lignite.—There is an abundance of lignite on the Muddy and its tributaries, and along the Missouri below Williston.

The following banks have been opened up for local use about Williston, and on the creeks to the north:

The Mackersie bank on Sandy Creek, in sec. 6, T. 154, R. 101.

The Holland bank near Muddy River, 6 miles north of Williston, where a heavy bed of lignite is exposed.

The Lovejoy mine on Stony Creek, where a considerable bed outcrops near the Great Northern Railway.

The mine of the Pioneer Coal Company, which is more extensively developed than any of these, and is shipping lignite in considerable quantities. It is located on the railroad, which here follows the valley of Stony Creek, in sec. 26, T. 15, R. 100. The bed mined is 6 feet thick.

The Miller mine, located 4 miles east of Williston on Cedar Coulee, a tributary of the Missouri. A 12-foot bed here outcrops and will furnish a vast amount of excellent coal.

A number of lignite outcrops 4 to 6 feet thick, which occur along Cow Creek, a tributary of the Muddy, and are mined to some extent for local use.

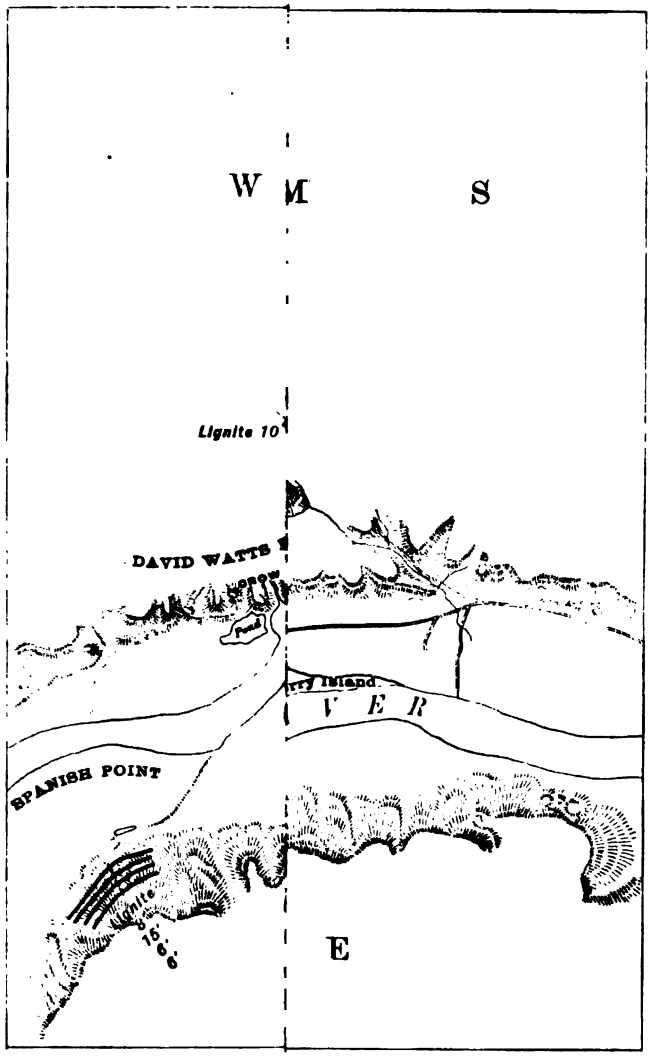
The old Dahl mine, 3 miles southeast of Williston, located on a 4-foot outcrop in the Missouri River bluffs on the left bank of the river.

Eight lignite beds, the heaviest being 4 feet thick, which outcrop in a single vertical section a mile farther down the river on the right bank.

NESSON-HOFFLUND FLATS.

The post-offices of Nesson and Hofflund are situated on Missouri River about 30 miles east of Williston and 14 miles south of the Great Northern Railway, the nearest station being the town of Ray; Hofflund is 6 miles east of Nesson. In this vicinity the Missouri receives a number of tributaries; Tobacco Garden and Clark creeks unite with it from the south, and Tobacco and Beaver creeks and White Earth River from the north.

Area and soil.—Two extensive flats or terraces are developed here, one from 20 to 40 feet above high water, extending about 6 miles along the river from Nesson to Hofflund, and the other from 80 to 100 feet high, located back of Nesson. The upper flat includes 7,500 acres held by more than 30 homesteaders and settlers; the lower includes about 6,000 acres. The soil of the upper, excepting a narrow gravelly strip along the lower edge, is composed of sandy loam with clay subsoil; that of the lower is of 1 to 4 feet of fertile sandy loam, with sand for a subsoil. Only a portion of the lower flat is wooded, the woodland at this point being confined principally to the flood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S
Lignite 10'
DAVID WATTS
Pond
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SPANISH POINT
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plain, which is not here considered a part of the lower terrace. A portion of this terrace is being carried away by inroads of the river, but the loss due to this cause is not serious enough to interfere with any scheme for the development of the flat as a whole. The slope of the surface of both terraces is favorable to irrigation.

For many reasons the region invites study with reference to the possibility of irrigation. The area, especially when both terraces are taken together, is considerable, the soil is inviting, and the distance from a railroad shipping point in only 14 miles. Heavy seams of lignite of good quality outcrop in the immediate vicinity, and a pumping station that would furnish water for the lower flat (6,000 acres) may, it is thought, be placed close to one of these outcrops, and the expense of hauling fuel may thus be greatly reduced or wholly obviated.

Water supply.—On account of the lift it will hardly be practicable to irrigate the upper flat with water drawn from the river, but Tobacco, Nelson, and Beaver creeks may be considered as possible sources of supply.

Tobacco Creek, which unites with the Missouri at Nesson post-office, has a drainage area of 20 square miles, and is fed by strong springs. Cusack Springs, at the source of its west fork, in sec. 12, T. 154, R. 98, are perennial and flow 3 second-feet even in midsummer. Deer Coulee heads at a spring about as strong as the Cusack and unites with Tobacco Creek a few miles above Nesson. During the summer the creek suffers some loss of volume because of the porous nature of the stream bed at some points. On July 4, 1903, it had a flow of 5 second-feet at its mouth, an amount somewhat less than that of its spring sources.

At least two suitable reservoir sites seem to exist on Tobacco Creek, one occurring a mile back of the upper Nesson flat, where the creek emerges from the bluffs. Another site with apparently a larger capacity occurs 5 miles farther up the creek. However, the ability of the creek to furnish water enough to fill extensive reservoirs has not been demonstrated. Nelson Creek, which drains 40 square miles, could also be used, as it is now used in a measure, in irrigating the upper flat. It is spring fed, though the springs are weak, and most of its available water is due to the melting of snow. In another chapter the tracts at present irrigated in this vicinity will be noted.

Beaver Creek drains 120 square miles in the southeastern part of Williams County. On reaching the Missouri River flats it turns to the east and its bed gradually becomes ill defined, and at last its water is spread over the nearly level surface. Six miles above its mouth, on July 8, the flow was 18 second-feet, which was considerably more than the flow nearer the mouth. In the spring of an ordinary year the discharge is considerable. The descent of the

stream is rapid, and it seems possible to utilize the water, if it can be properly stored, to irrigate at least a part of the upper terrace.

The water from these three creeks seems sufficient to irrigate the 7,500 acres on the upper flat, which, on account of their elevation of from 80 to 100 feet, may not profit by any scheme to utilize the water of the Missouri.

On these creeks bowlders are fairly abundant. Aside from these, and beds of soft sandstone, no other stone occurs in the vicinity that could be used in reservoir construction.

Lignite.—For the lower flat, which includes 6,000 acres, pumping from the Missouri may be practical, for fuel is abundant, as shown by the following list of lignite outcrops that occur in this region. At Spanish Point, on the opposite side of the river and 4 miles farther up, four heavy beds outcrop in the bluffs. The aneroid gave the following elevations for the beds:

Relative altitudes of lignite beds near Nesson-Hofflund flats.

	Feet.
Top of bluff	2,850
Lignite, 3 feet, at	2,730
Lignite, 6 feet, good, at	2,690
Lignite, 15 feet, good, at	2,500
Lignite, 8 feet, good, at	2,450
High water of river, about	2,400

The elevations show merely the relative positions of the beds and may vary considerably from the absolute elevations. The bluff is one of the highest in the State.

On Deer Coulee, a tributary of Beaver Creek, at the Marmon ranch, 4 miles from Nesson, a 10-foot seam of good lignite outcrops, from which a strong spring issues. A seam of similar thickness is reported at a number of points at about the same elevation as this outcrop, and the bed may be regarded as rather extensive.

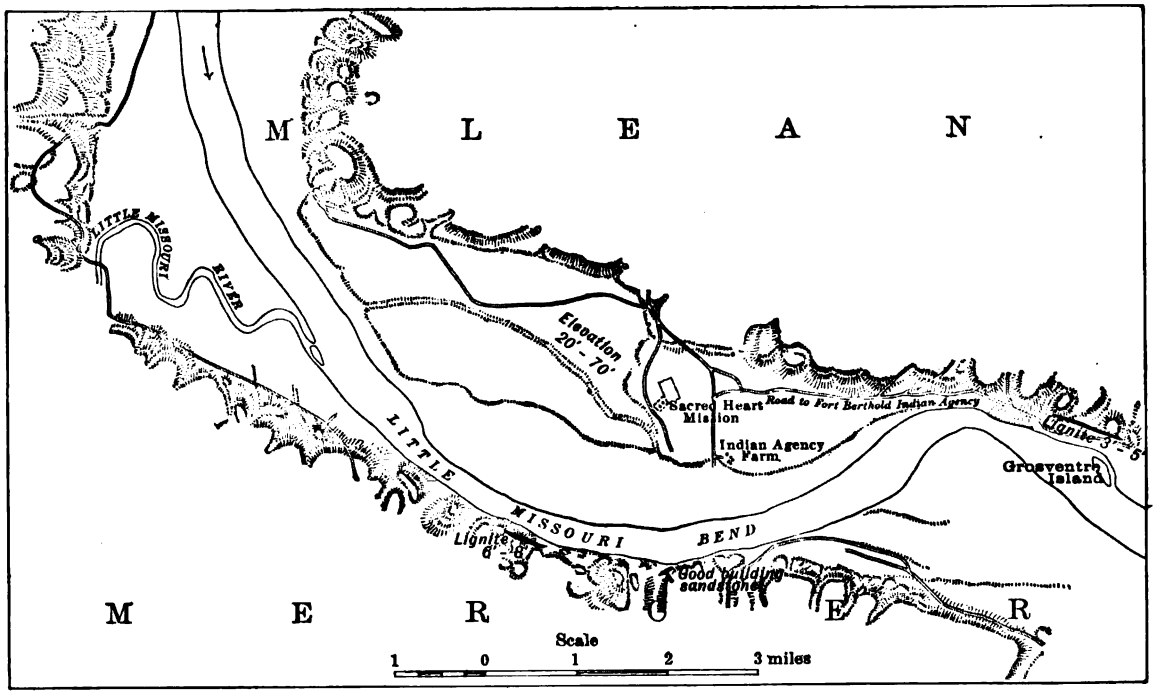
Along Tobacco Creek two seams, 6 and 8 feet thick, outcrop at a number of points, both seams often being exposed in the same vertical section. They can furnish large quantities of good lignite.

On Beaver Creek a 4-foot bed outcrops frequently and is used locally. Three miles above Hofflund a 10-foot bed is mined somewhat more extensively. An entry has been carried in 30 feet; this lies so low that in high water it is partly filled from the creek.

In the bluffs across the Missouri Mr. H. A. Carey takes coal from a 6-foot seam.

Lauchland's bank, located close to the west end of the lower flat, is said to show a good bed of lignite about 8 feet thick.

At Stony Point, on the right bank of the river between Nesson and Hofflund, two beds of good lignite, each 3 feet thick, were seen, and



MAP OF NEW FORT BERTHOLD AGENCY FLATS, ELBOWOODS, N. DAK.

a heavier bed is said to outcrop at this point. Pl. II illustrates the two flats and gives the location of some of the lignite outcrops.

FORT BERTHOLD AGENCY FLATS.

Area and soil.—The flats about the present agency on the Fort Berthold Reservation, which are low enough to justify study with reference to irrigation by pumping from the Missouri, include 5,000 acres. Of this perhaps 1,200 acres, which were formerly woodland and have been recently burned over, are now practically clear, while 800 acres are still covered with large trees. This woodland area is but 20 feet above high water, has a sandy loam soil, and is very rarely covered by water during ice gorges. Twenty feet above this lies a well-grassed flat of 1,200 acres, and still higher, perhaps 80 feet above the river, is a terrace containing about 2,000 acres.

Lignite.—Lignite outcrops frequently in the vicinity. Just across the river, at high-water level, a bed of 3½ feet of lignite was exposed; the whole bed was reported by the superintendent of the agency to be 10 feet thick. It has supplied coal for the agency during the winter when the river has been low and crossing on the ice possible.

In the bluffs 3½ miles below the agency and on the same side of the river a 9-foot bed with 1 foot of clay in the middle outcrops 50 feet above the low river flat. A half mile farther south the following section is exposed:

Section near Fort Berthold Agency, N. Dak.

	Feet.
Lignite, 6 inches of clay in the middle	6
Clay	20
Lignite	2
Clay	5
Lignite	2
Clay	50
Slope to low river flat	20

All of the lignite in this section seems to be good.

Seven miles below Fort Berthold Agency Mr. W. C. Dean reports a 12-foot bed of lignite, from which he hauls coal to the agency.

Lignite in beds of workable thickness outcrops in the bluffs back of Elbowoods at a number of points. The flats with lignite in the vicinity are shown on Pl. III.

OLD FORT BERTHOLD AGENCY FLAT.

This flat, which is about 12 miles below the present agency, contains about 4,000 acres, which are well grassed. Its elevation is from 20 to 80 feet above Missouri River, which bounds it on the

south. In the bluffs just east of the flat a 5-foot bed of good lignite is exposed about 50 feet above the river. On the opposite side of the river a 5-foot bed is mined by stripping. A 4-foot and a 3-foot seam outcrop in the bluffs a mile south of this mine.

FORT STEVENSON FLATS.

These beautiful flats, which include about 7,000 acres, lie on the north side of the river, a few miles northeast of Coalharbor (Pl. IV, A). Their elevation is from 30 to 70 feet above the Mis-

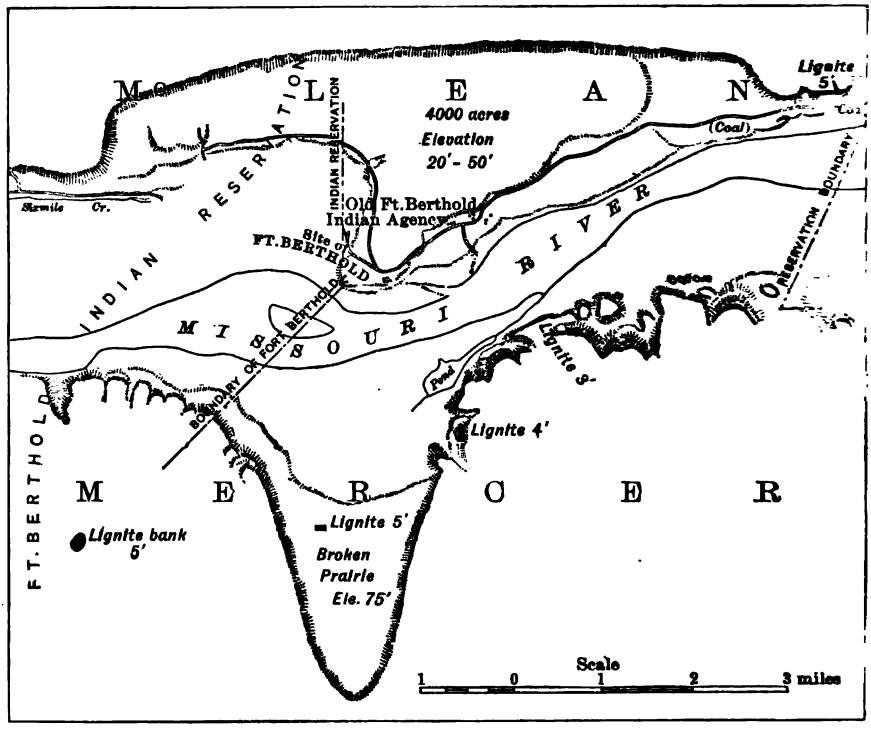
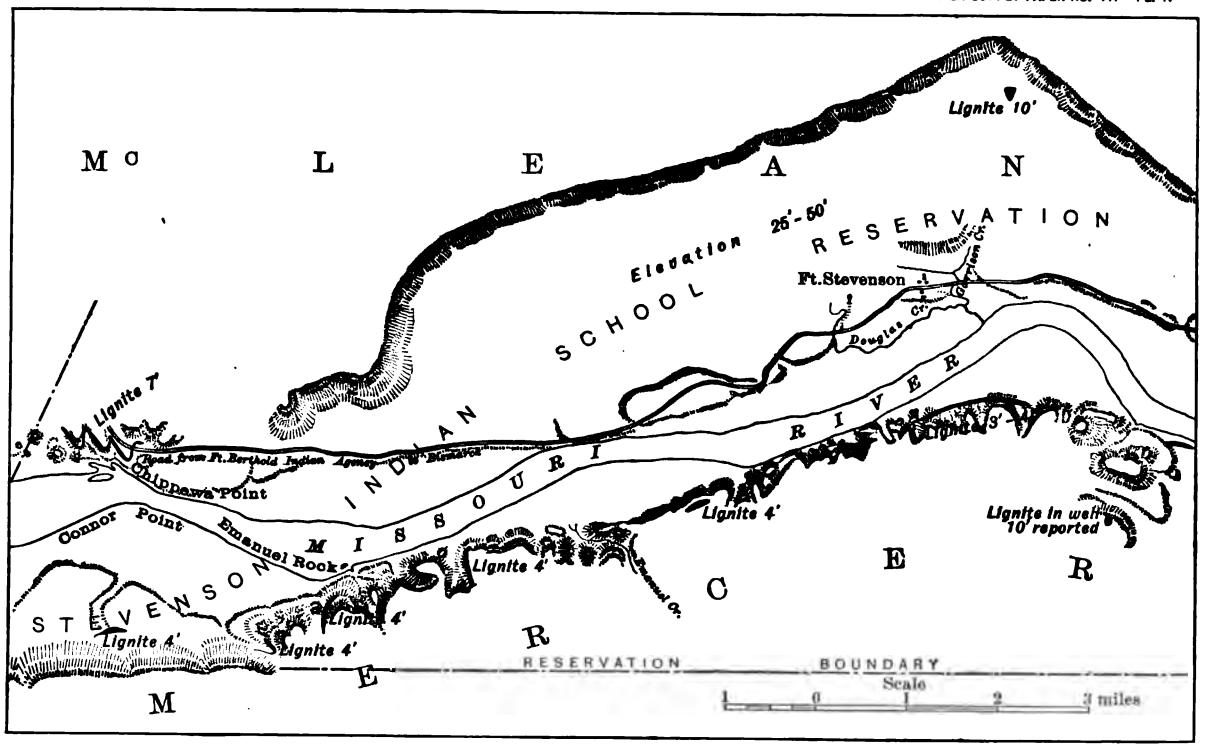


FIG. 2.—Map of flats about old Fort Berthold Agency, N. Dak.

souri. The slope from the bluffs to the river is gradual and uniform. Coal occurs abundantly in the bluffs just back of the flats. For many years lignite was mined here for use at the fort and the Indian school formerly located here. The exact location of the mine was SW. ¼ sec. 35, T. 148, R. 85. A seam said to be 14 feet thick was mined by stripping. On the opposite side of the river seams 3 to 4 feet thick are nearly continuous in outcrop for 10 miles.

APPLE RIVER FLATS.

Just south of Bismarck are extensive triangular flats, which lie between Missouri River on the west, Apple River on the east, and the



MAP OF FORT STEVENSON FLATS.

A. A 5-FOOT LIGNITE BED ON THE MISSOURI ABOVE COALHARBOR.

B. SAGEBRUSH FLATS ON THE LITTLE MISSOURI.

bluffs back of Bismarck on the north. They have an area of about 5,000 acres, 2,000 acres being only from 20 to 30 feet above the river and partly wooded, while the rest are from 80 to 100 feet above river level. No coal outcrops in the immediate vicinity, but the expense involved in bringing lignite from the thick beds outcropping directly on the river 60 miles above, at Mannhaven and Coalharbor, should not be great. It may be more practical to control the water of Apple River and use it for irrigation purposes, for the stream drains a considerable area and could doubtless furnish all the water needed if it could be properly stored.

On account of their situation on the outskirts of a city of considerable size and on the Northern Pacific Railway gardening should prove remunerative, and a rather high cost per acre to secure irrigation may be justified.

BIG BEND AND SHELL CREEK FLATS.

Area and soil.—The Missouri River receives the waters of the Little Knife just before entering the Fort Berthold Reservation. Then, instead of pursuing its normal course, it makes a notable bend like a great letter U, which is known as the "Big Bend." Throughout this portion of its course, and in the valley of Shell Creek, which meets it at the lower end of the U, topographic conditions and heavy beds of lignite invite a careful study with reference to irrigation possibilities, though the conclusions that may be reached are probably more uncertain than in the flats already described. The area, however, is large, and as the land lies wholly within the reservation it is still completely under Government control.

The river at the "Big Bend" seems to have been diverted from its course at some time in the past, perhaps by the Wisconsin ice sheet, and compelled to cut a new channel to the west. Its former channel seems to connect the two arms of the U, and to form a valley 2 miles in width, with its center, a third of a mile wide, sloping very gently and unbroken by gullies. Its position with reference to the river and Shell Creek is shown on Pl. VI. At the upper end of the U this old valley is 140 feet above the river; its slope is toward the south, the upper half draining into a large slough in its center, while the lower portion contributes its water to Shell Creek. The area that could be irrigated advantageously, if water could be found, is two-thirds of a mile wide and 15 miles long and includes about 7,000 acres of good soil. In addition to this, on the Missouri at either end of this old valley are flats which contain 3,000 acres.

Lignite.—At the point marked A in Pl. VI, 6½ feet of good lignite outcrops in the bottom of a draw about 80 feet above the river without revealing the bottom of the seam. One-half mile down the

river in the bluffs at the point marked B, the following section is exposed:

Section at Big Bend, Missouri River.

	Feet.
Lignite	5.5
Clay	5.0
Lignite	7.0
Clay	50.0
Water level.	

One hundred yards farther down, a section partly covered by talus gave:

Section at Big Bend, Missouri River.

	Feet.
Lignite	4.5
Clay	5.0
Lignite	3.0
Clay	50.0
Water level.	

The quality of the lignite in all of these beds is good.

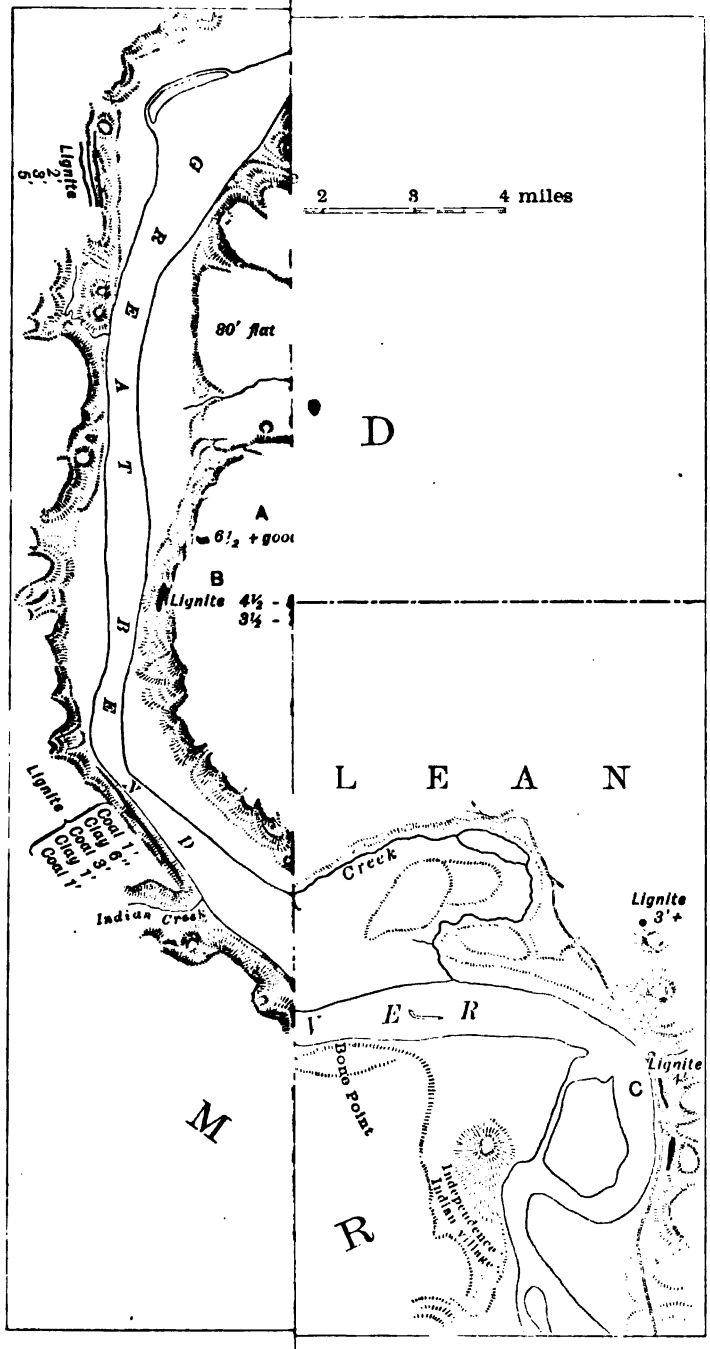
Just below Shell Creek, at the point C on the map (Pl. VI), 3½ feet of good lignite outcrops in a cut bank known as "the slide." This same seam probably gives rise to the spring in the bluffs 2 miles to the north, where the Indians have dug through 2 feet of lignite to give freer vent to the water. It is persistent in outcrop for 3 miles to the south, though showing but few good natural exposures. Although the exposures noted indicate a great abundance of lignite in seams from 4 to 7 or more feet thick, the amount of the lift may render pumping from the Missouri out of the question. Shell Creek drains more than 125 square miles, and its water may be available at least for portions of the area and for areas of 600 to 1,000 acres found along its own valley. The flow of water in Shell Creek on July 17, 1903, was about 6 second-feet.

OTHER FLATS.

Some of the many flats on the Missouri, limited in extent, but not so high as to render pumping from the Missouri out of the question, should be noted in addition to the more extensive tracts already described. Much of the woodland on the upper edge of the flood plain can doubtless be cultivated after clearing, since the soil is generally fertile and the value as timber land small. These tracts however are not included in the flats mentioned below.

On the south side of the Missouri, at the edge of the old Fort Berthold Reservation, there is a flat of 1,200 acres lying 40 feet above the river; no coal appears in the immediate vicinity.

On Muddy River cut-off, about 10 miles below Williston, on the north side of the river, are 700 acres, 20 to 40 feet above the river; lignite 6 feet thick shows in the bluffs a mile below.


2 3 4 miles
Lignite
2'
3'
6'
80' flat
A
6½ + good
B
Lignite 4½ -
3½ -
Lignite
Coal 1'
Clay 6"
Coal 3'
Clay 1'
Coal 1'
Indian Creek
D
L E A N
Creek
Lignite
3' +
E R
Lignite
C
Dodge Point
Independence
Indian Village
M
R

At Barkers Bend is a good flat of 600 acres; 12 feet of lignite appears in "sliding bluff" just below.

Opposite Nesson there are flats containing 1,200 to 1,500 acres from 25 to 50 feet above the river; the heavy beds of lignite in Spanish Point, already described, are only 3 miles away.

Opposite the mouth of White Earth River is an area of 600 acres; there are three lignite beds, the thickest 4 feet deep, in the bluffs just behind.

Opposite the mouth of the Little Knife are 2,000 acres in two terraces, one 20 the other 40 to 80 feet above the river; one lignite bed 4 feet thick was found in the bluffs behind this flat.

At the Indian village of Independence are 1,000 acres 80 feet above the river; lignite outcrops in a 4-foot bed just across the river.

Five miles below the mouth of the Little Missouri, on the east side, is an area of 500 acres in two terraces; lignite outcrops in a 4½-foot bed just opposite.

Just below the Fort Berthold Agency, on the opposite side of the river, is a long narrow flat containing 2,000 acres, 15 to 25 feet above the river, extending to Little Beaver Creek; 4 feet of lignite outcrop in the river bluffs at the latter place.

Just above the town of Mannhaven are 1,500 acres 40 to 50 feet above the river; 8 feet of good lignite outcrop on the river at Mannhaven, with thinner beds, as shown in the following section:

Section near Mannhaven, N. Dak.

	Feet.
Lignite, good	6
Clay	2
Lignite	1
Clay	1
Lignite, good	2
Clay	10
Lignite, good	8
Sand	12
Water level.	

This section may be seen for 2,000 feet along the river.

At Hancock are 1,500 acres in a series of terraces 15 to 25 feet above the river; 4 feet of coal outcrops in the bluffs behind, while across the river the heavy beds, once developed and known as the "Plenty" mine, outcrop. The beds there exposed show the following section:

Section near Hancock, N. Dak.

	Ft.	in.
Lignite	3	
Clay	0	6
Lignite	3	
Clay	2	
Lignite	3	

Mr. F. G. Mattoon is putting in a pumping plant to irrigate portions of these flats.

Two miles above Stanton, on the opposite side of the river, are 1,000 acres, 15 to 25 feet above water level; a 7-foot lignite bed outcrops near the water on the edge of the flat.

Opposite Washburn are 3,000 acres in three terraces, portions of which are subject to irrigation; 6 lignite exposures, showing from 3 to 7 feet of coal, occur in the bluffs and coulees behind the flats.

At Painted Woods Lake are flats containing 3,000 acres; there are 4 feet of lignite in a neighboring draw and a 5-foot bed exposed on a creek on the opposite side of the river near Sanger court-house.

At the mouth of Square Butte Creek, 8 miles above Mandan, flats occur; 2 feet of lignite are reported 2 miles to the north.

Near Mandan and at a number of points farther down the river are extensive flats; no heavy beds of lignite are known to occur near them.

LITTLE MISSOURI RIVER FLATS AND LIGNITE.

Terraces are well developed along the Little Missouri at nearly every point in its course. In a given locality their number may be five or six, and few localities have less than three. Their elevation varies from 20 to 200 feet above the river. No single tract is large, on account of the meandering of the river, but the total area at an elevation moderate enough to make pumping from the river practicable is considerable. A rather careful estimate of the area not more than 30 feet above the river places it at more than 30,000 acres, cut up into tracts ranging in size from 50 to 1,000 acres.

FLATS AND LIGNITE IN THE VICINITY OF YULE.

During the summer of 1902, 9 townships on the upper course of the Little Missouri, with Yule post-office as a center, were studied. There is much diversification in the topography of the country, which includes Little Missouri Valley and its terraces, the "breaks" in the vicinity of the river, and the rolling country back from the river, which furnishes an unequaled summer range for cattle.

Lignite.—Lignite outcrops almost continuously, even in the shallowest of coulees, as well as along the creeks and on the main stream itself. These outcrops are from 6 inches to 40 feet in thickness. Ranchmen seldom find it necessary to go far for fuel. Many of them consider it easier, however, to go to the river in winter and break up the great blocks of coal that the stream has washed out. There are a number of small flats on this stream south of Medora which lie well for irrigation by pumping. More than half of the area had not been surveyed in September, 1902, and it is impossible to cite locations definitely in many cases.

TOWNSHIPS 133 AND 138, RANGE 105.

In townships 133 and 138, range 105, which includes an area from 20 to 40 miles south of the Northern Pacific Railway, are the heads of a number of coulees, which flow eastward into Little Missouri River. In going from north to south, Williams, Garner, Bull Run, Horse, Coal Canyon, Cannonball, Boise, and Bacon creeks are crossed, in about the order named. All of these creeks show lignite more or less continuously from the time that they cut through the sod till they empty into the Little Missouri; their courses vary in length from 10 to 20 miles. None of them, except Cannonball, are shown on an ordinary map.

On Williams Creek, 6 miles from its mouth, the following section is given:

Section on Williams Creek, North Dakota.

	Feet.
Lignite, good	2
Clay	20
Lignite, good	4
Clay	4

Lignite, 1 foot exposed; bottom of bed not found.

These beds were traced for a mile along the creek. Along the lower course of the stream lignite is said to be abundant.

On Garner Creek exposures of lignite are not abundant, though springs that probably come from the lignite are common, the lignite being concealed by the grassed slopes. A tributary which unites with the creek 8 miles above the Little Missouri is said to show a 4-foot bed.

On Horse Creek for more than 6 miles lignite beds varying in thickness from 3 to 6 feet are exposed at various elevations.

On Coal Canyon Creek an abundance of lignite is exposed along the deep ravine through which the stream flows. A typical section is as follows:

Section on Coal Canyon Creek, North Dakota.

	Feet.
Lignite, fair	5
Clay	1
Lignite, good	7
Clay	1
Lignite, good	1

Creek bottom.

This exposure occurs 2 miles west of the Little Missouri.

On Cannonball Creek, which empties into the Little Missouri about 25 miles south of Medora and is a stream of some importance, its valley being nearly a mile wide a mile from its mouth, there are 6 feet of good lignite outcrop in a single bed. Along the Little Mis-

souri and its tributary ravines in this vicinity 4 or 5 beds of lignite may be seen, ranging up to 4 feet in thickness.

On Boise Creek, some miles above its mouth, 2 or 3 beds were seen, ranging from 2 to 4 feet in thickness.

On Bacon Creek, at the J. C. Gamel ranch, in sec. 20, T. 133, R. 104, a bed 24 feet thick outcrops. Its quality is good.

On Sand Creek a lignite bed 40 feet thick outcrops near the A. E. Russel ranch, in sec. 31, T. 135, R. 101. The exposure is continuous along the creek for a quarter of a mile, and much of the coal can be obtained by stripping less than 10 feet of earth from the surface. At the north end of the exposure the section given was:

Section on Sand Creek, North Dakota.

	Feet.
Sandstone	2
Clay	10
Lignite	2
Clay	2
Lignite	15
Clay	3
Water level.	

At the south end of the exposure the lignite reached the remarkable thickness shown below:

Section on Sand Creek, North Dakota.

	Feet.
Clay	5
Lignite	3
Clay	2
Lignite	40

The lignite throughout the bed appeared to be of good quality, except that the upper 2 feet were soft. The analysis indicates good quality.

On the Little Missouri near the 777 ranch, a few miles south of Yule, some fine beds outcrop. Rising directly from the water's edge at one point, the beds of clay and lignite reach a height of 110 feet, as shown in fig. 3. The heaviest lignite bed in the section is the lowest, which is more than 12 feet thick.

At Yule and at points between it and Medora 2 or 3 beds of fair thickness and quality occur.

Area.—Well-developed river flats occur along the Little Missouri in this vicinity, at times exceeding 500 acres in extent.

FLATS AND LIGNITE AT AND BELOW MEDORA, N. DAK.

In the Little Missouri Bluffs at Medora, on the Northern Pacific Railway, the section shown in fig. 4 may be seen. The lignite in all the beds is of good quality. It outcrops repeatedly on the west side of

the river. Both north and south of Medora for a number of miles lignite is as abundant as at the points cited. At some points, as near the Eaton ranch, it is mined for local use.

The larger flats along this portion of the Little Missouri are noted below, with the amount of lignite known to occur in their vicinity. The land has not yet been surveyed, and locations are noted by referring to ranches in the vicinity.

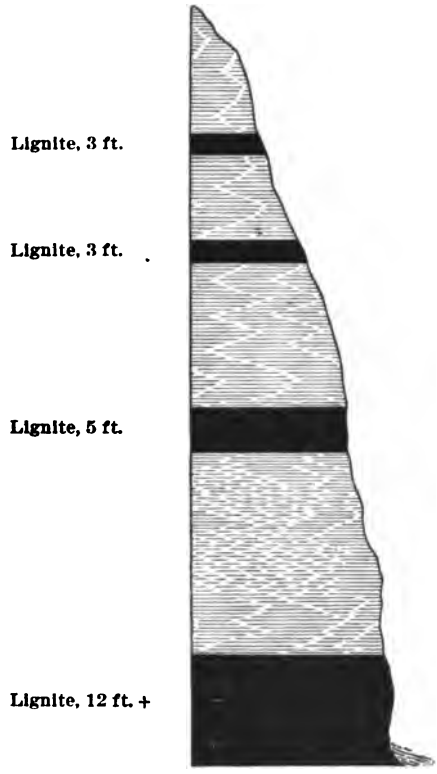


FIG. 3.—Section 30 miles south of Medora, at the 777 ranch, showing lignite seams.

Near the Burgess ranch, 4 miles north of Medora, are several flats from 50 to 160 acres in extent; lignite appears in three beds, each from 3 to 4 feet thick.

Between Burgess and Parkin's ranch, five miles north of Medora, are flats amounting to 400 acres, 100 acres of which are about 25 feet above the river; two lignite beds 4 to 8 feet thick appear.

Near Young's ranch are flats containing 400 acres; lignite occurs in large quantities on Government Creek.

From Young's to Johnson's ranch are flats containing 300 acres.

Near Mikkelson are flats containing 250 acres, 25 feet above the river, and 100 acres in addition in the vicinity; lignite is present in four beds, each from 3 to 5 feet thick; 2 miles below Mikkelson a 18-foot bed is exposed in a small butte. (Pl. VII, *B*.)

Near Carter's ranch, 3 miles below Mikkelson, are flats containing 250 acres and on the opposite side of the river 160 acres; lignite is abundant in the vicinity, a 9-foot bed outcropping 2 miles below the last-named flat.

Between Medora and the mouth of the Little Missouri several small flats ranging from 50 to 500 acres occur, which are from 15 to 30 feet above the water; lignite is abundant all along this portion of the river and is of good quality.

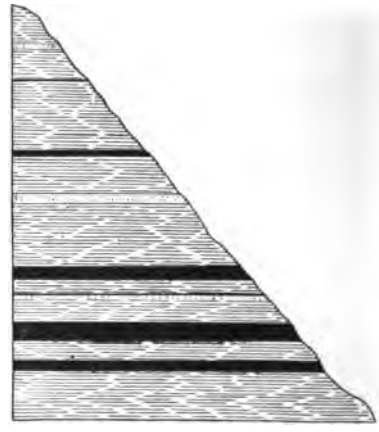


FIG. 4.—Section showing lignite seams in the bluffs at Medora.

Near President Roosevelt's old ranch are flats which have an area of 200 acres; there is a 5-foot lignite bed in the adjacent draw.

Near Clark and Morgan ranches large flats occur at the mouths of Blacktail and Whitetail creeks, which here unite with the Little Missouri from the east; they include 400 to 600 acres, with a 10-foot lignite bed outcropping just across the river and 3- to 4-foot beds showing on the same side.

Near the mouth of Beaver Creek, both on this creek and on the Little Missouri, are large flats, the total area practicable for irrigation being more than 600 acres. (Pl. VIII, *A*.) Lignite in beds 3 to 4 feet thick may be seen at a number of points in adjacent bluffs.

Near Simpson's ranch and Magpie Creek is an area of 500 acres, from 15 to 25 feet above the river, broken into three tracts; two beds of lignite are exposed near by, each 3 feet thick.

A. AN 8-FOOT LIGNITE BED 8 MILES NORTH OF MEDORA.

B. AN 18-FOOT LIGNITE BED 2 MILES BELOW MIKKELSON.

Near Gore brothers' ranch are level flats containing 200 acres 15 to 25 feet above the river; lignite appears in two 3-foot beds.

Near Martin's ranch and Bolan and Redwing creeks is a 200-acre flat; there are lignite beds from 2 to 10 feet thick.

CHERRY AND TOBACCO GARDEN CREEK FLATS.

Area and water supply.—From the first permanent eastward bend of the Little Missouri northeast to the Missouri there extends an ancient river valley, drained by Cherry Creek into the former stream and by Tobacco Garden Creek into the latter, and also by the greater parts of Redwing and Bolan creeks.

This valley is indicated by broken lines on Pl. I; it seems to mark the course of the Little Missouri during some pre-Glacial period. It is about 30 miles long, and from 1 to 5 miles wide.

The highest point of the old valley is Bear Butte, which forms the divide between Redwing and Cherry creeks. Numerous tributaries, which carry considerable water in the spring, but are dry in the summer, enter both Cherry and Redwing creeks as they flow through the old valley. Most of these tributaries head in the divide between the Yellowstone and Little Missouri, and attain a maximum length of 4 or 5 miles. They are significant in connection with the irrigation of the valley, for land here is being taken under the desert land act, the intention being to irrigate by building reservoirs in the small tributaries to the creeks just named.

The bluffs back of the old valley are very abrupt. Under present conditions the most fertile portion of the valley is found on the upper part of Cherry Creek. The X ranch, owned by the Converse Cattle Company, grazed nearly 5,000 cattle on this portion of the valley during the entire summer of 1902. Irrigation by means of reservoirs in the tributary creeks and coulees is practicable to some extent.

FLATS AT AND BELOW FORT BERTHOLD.

After entering the Fort Berthold Reservation the flats on the Little Missouri become insignificant.

LIGNITE OUTCROPS.

A list of the more important lignite outcrops on the Little Missouri, and their position with reference to the river and flats, is given in the following table:

The more important lignite outcrops on Little Missouri River, North Dakota.

Location.	Number of beds.	Thickness in feet.	Extent of outcrop.	Elevation above river.	Distance from river.	Distance from flats.
4 miles from Medora, in buttes.	1	10	20 feet	225 feet	2½ miles	2½ miles.
Opposite Burgess's ranch.	1	3	20 rods	River level.	On river	40 rods.
	1	8				
2 miles below Burgess	1	5	4 rods	do	do	A few rods.
	1	6				
5 miles blow Burgess	1	3	Several rods.	do	do	1 mile.
	1	5				
3 miles west of Parker's ranch.	1	3	do	8 and 15 feet	do	
	1	3				
3 miles east of Young's ranch.	1	3		200 and 300 feet.	3 miles	3 miles.
	1	10				
2 miles south of Mikkelson	4	17 to 18	10 rods	Near water	On river	1 rod.
2 miles north of Mikkelson	1	16	6 rods	Water line.	do	¼ mile.
Reed's ranch	1	8	Several rods.	40 feet	do	Just across the river.
	1	10				
Mouth of Beaver Creek	1	3	1 mile	20 to 40 feet.	do	Across river.
	1	8				
Near Morgan's ranch	1	3	do	River level.	do	Edge of flats.
	1	7	½ mile	30 to 60 feet.	do	40 rods.
	1	10	1 mile	30 feet	10 rods	80 rods.
Near Simpson's ranch	2	6 to 8	½ mile	0 to 60 feet.	On river	Across river.
Bolan Creek	1	10 to 12		100 feet	1½ miles	2 miles.
	4	3 to 4				
Redwing Creek	1	10 to 12		do	1 mile	½ mile.
	1	4			On river	¼ mile.
Boehm's ranch	1	3 to 4	10 rods			Across river.
Squaw Creek	1	4 to 5	14 rods	300 feet	1 mile	¼ mile.
	1	4 to 5	4 rods	200 feet	do	1 mile.
Near southwest corner Indian reservation.	1	12	2 to 3 miles			A few rods.
Near Manning's ranch	1	12	20 rods	10 to 20 feet.	On river	40 rods.
	1	5 to 6	do		do	Do.

A. FLATS ON LITTLE MISSOURI RIVER NEAR BEAVER CREEK.

B. AN 8-FOOT BED OF LIGNITE ON LITTLE MISSOURI RIVER ABOVE REED'S RANCH.

FLATS AND LIGNITE ON KNIFE RIVER AND TRIBUTARIES.

FLATS.

Knife River.—The Knife River flats are like those along the Little Missouri just described, differing mainly in not being so shut in by high bluffs and in having the slopes to the uplands comparatively gradual.

The flow of water in Knife River even in summer is often considerable. On July 31, 1903, it was too deep to ford near its mouth, and when seen again at the same point on August 21 there was a foot of swiftly flowing water over the fords, which were 25 feet or more wide.

For 15 miles from its mouth the flats are extensive, often reaching a width of a mile and including in all about 4,000 acres, which lie from 15 to 25 feet above the river. Lignite is found along all the bluffs at the mouth and outcrops in nearly every coulee. An 8-foot bed is mined 4 miles south of the river on the west bank of Brody Creek.

Below Hazen the river flats within 4 miles embrace 2,500 acres. A 4-foot lignite bed is found 4 miles north of Hazen. From Hazen to the mouth of Spring Creek, the main tribuary of Knife River, a distance of 10 miles, are flats that lie 20 feet above the river and have an area of 2,000 to 3,000 acres.

From Broncho to Rock Springs, on Knife River, the average width of the flats is one-half mile, and the total acreage considerable. Four feet of lignite outcrop in sec. 14, T. 143, R. 94.

Spring Creek.—Flats extend up Spring Creek for a mile, above which to Halliday they are cut up into small tracts of 30 to 40 acres. Lignite in two beds outcrops near O'Neil's ranch.

From Halliday to Pelton's ranch, on Spring Creek, a distance of about 12 miles, flats are extensive and include about 4,000 acres. Spring Creek is perennial, and its flow is considerable. At Paulson's ranch a 16-foot bed of good lignite outcrops. It is covered by only 10 to 20 feet of clay, and furnishes fuel for the neighboring ranches. There is much coal in the vicinity of Halliday, as shown by springs and outcrops along the creek. At Olafson's ranch two beds of good lignite 2 and 3 feet thick outcrop on the north side of the creek. Six miles north of Halliday on Hans Creek a spring, which issues from a lignite outcrop, is used for irrigation. On the south side of this creek a bed said to be 10 feet thick is mined in winter.

Farmers Valley.—Farmers Valley, which extends from Hebron to a point north of Gladstone, and then north through Deep Creek Valley to Rock Spring post-office, contains 10,000 acres of land fit for irrigation if water could be found. In sec. 33, T. 141, R. 93, a possible reservoir site exists.

LIGNITE OUTCROPS.

The following table gives the more important lignite outcrops on Knife River and Spring Creek and their position with reference to river flats:

Lignite outcrops on Knife River.

Location.	Number of beds.	Thickness in feet.	Extent of outcrop.	Elevation above stream.	Distance from stream.	Distance from flats.
Sec. 9, T. 144, R. 89, G. Weige	1	5 to 6	10 feet		On creek.	On edge of flat.
2½ miles east of Weige	1	10	20 rods	Taken on report; said to be on edge of flat and accessible.		
5 miles west of Weige	1	5	10 rods			Edge of flat.
Olafson's at Halliday	2	2 to 3	do		On creek.	Edge of 200-acre flat.
Opposite Halliday	1	5	5 rods		do	Faces flat.
Sec. 15, T. 145, R. 92	1	4	4 rods		1 mile	
Anderson's, sec. 28, T. 146, R. 92.	1	[a] 10			7 miles	
Paulson's, sec. 27, T. 145, R. 93.	1	16	40 rods		On creek.	Near 400-acre flat.
Paulson's, sec. 12, T. 142, R. 93.	1	5 to 6	5 rods	30 feet		Near 600-acre flat.
Corey's, sec. 28, T. 144, R. 96	1	4	Extensive			
Beck's, sec. 4, T. 144, R. 97.	1	[b] 4		This bed is on Little Knife, between Fayette and Richardton.		
Fayette	1 1	2 to 3 4	20 rods	Beds run along creek at elevation of 10 feet; 6-foot bed reported 6 miles west.		
Brannen's, sec. 34, T. 144, R. 99.	1	5		Placed upon the Little Missouri divide.		
5 miles south of Brannen's.	1	5		Extends along draw for several miles.		
Sec. 13, T. 141, R. 93, north of Richardton.	1	4				Near 600-acre flat.
2½ miles northwest of Richardton.	1	4				
Sec. 33, T. 141, R. 93	1	4				
Sec. 14, T. 143, R. 94	1	4	40 rods	20 feet	On creek.	Do.
Sec. 13, T. 143, R. 94; O. Ziner's.	1	3 to 4				2½ miles.
Sec. 15, T. 143, R. 94; Bailey.	1	4	5 rods		Near Knife River.	Near 1,000-acre flat.
Secs. 9 and 2, T. 142, R. 92; M. Hanson.	1	5 to 6				Near 600-acre flat.
Secs. 5, 7, and 9, T. 140, R. 90; Crowleys.	1 1 1	3 to 4 3 to 4 6 to 8				
Sec. 4, T. 142, R. 90; F. M. Smith.	1	4 to 5				Near 200-acre flat.
Sec. 14, T. 143, R. 89; Gerechts.	1	5 to 6				

[a] Reported. [b] At spring.

On the lower Knife River lignite is obtained at many points on the north side of the stream. The bed is 3 to 4 feet thick. Lignite may also be obtained from a bank 4 miles south of Hazen, where the bed is 8 to 10 feet thick.

FLATS AND LIGNITE ON HEART RIVER AND TRIBUTARIES.

FLATS.

Attractive flats, each containing a few hundred acres, may be found along Heart River and its tributary, Green River.

LIGNITE.

Heart River.—Lignite outcrops are frequent along both the Heart and the Green, some of the largest mines in the State being located in their vicinity. The New Salem mines, only 12 miles north of Heart River, had an output of 17,000 tons during the year 1902–3. Other mines at Sims, no farther from the river, are producing extensively. Between New Salem and the river 5-foot beds outcrop at a number of points and are mined on the strip-pit plan.

The mine of the Consolidated Coal Company at Lehigh, 3 miles east of Dickinson, has developed a remarkably fine bed of lignite

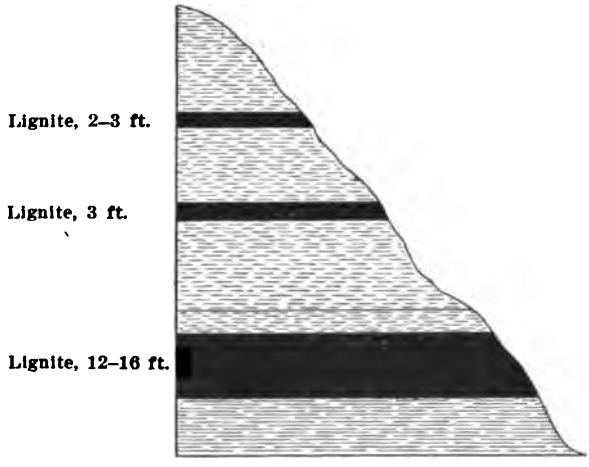


FIG. 5.—Section at the Lehigh mine.

which varies in thickness from 12 to 16 feet. It outcrops continuously along the river for 3 miles. Thirty feet above this thick bed a 3-foot bed is frequently exposed, and above this another and more variable bed. (Fig. 5.)

At two points on the outskirts of Dickinson lignite is mined in considerable quantities. At the plant of the Dickinson Pressed Brick and Fire Clay Company a 5-foot bed is mined by stripping. The Lenneville mine, half a mile east of Dickinson, shows a bed varying in thickness from 4 to 8 feet. Lignite from this mine ordinarily sells for $1.50 per ton at the mine.

Three and 4 miles west of Dickinson, on Heart River, a 4-foot and a 7-foot bed outcrop frequently. The lignite at the Bird-Stone mine, in sec. 6, T. 139, R. 98, outcrops on Heart River, and may be seen from the Northern Pacific Railway. The bed is 16 feet thick, the upper part being inferior in quality at the outcrop; the lower 8 feet is excellent. In section 8 of the same township the bed outcrops again. On the south side of the Little Heart, between South Heart and Belfield, a 6-foot bed of excellent coal occurs. It may be seen best in sec. 16, T. 139, R. 98, a school section.

Green River.—North of Dickinson lignite abounds on Green River throughout its course. Near its mouth at Gladstone beds of excellent quality, though not exceeding 5 feet in thickness, are found on the Rust and A. B. Powers farms in secs. 26 and 27, T. 140, R. 95. The exposures are directly on the river and near water level. Two miles farther up the stream, in W. ½ sec. 22, T. 140, R. 95, a 3-foot bed of good lignite is mined by the owner of the ranch on which it occurs. At the Kupper ranch, due north of Dickinson, a 15-foot bed of excellent lignite outcrops for a long distance on the edge of Green River. This bed is known to be very extensive.

Coalmine Creek.—Coalmine Creek, a tributary of Heart River, which unites with it a mile east of Belfield, shows great quantities of lignite along its course for at least 5 miles. Two good banks were examined, one 6 feet thick in sec. 28, T. 140, R. 98, the other 7 feet thick in sec. 27, T. 140, R. 98. A number of additional openings have been made along this creek from which lignite is taken. In sec. 30, T. 140, R. 99, 5 feet of a bed said to be 9 feet thick may be seen.

Norwegian Creek.—Three miles south of Belfield, on Norwegian Creek, a tributary of the Little Heart, which flows east and unites with the Little Heart 8 miles southeast of Belfield, a number of beds are exposed and slightly opened. They include the Englehardson bank, in sec. 20, T. 139, R. 99, with lignite 6 feet thick, and the Anderson bank in section 19 of the same township, with a bed 12 feet thick. In the vicinity of all of these lignite outcrops there are flats of moderate elevation.

FLATS AND LIGNITE ON CANNONBALL AND CEDAR RIVERS.

Terraces of different elevations, with a considerable total area, occur along the course of the Cannonball below its union with the Cedar and along both streams for 60 miles above their junction. On account of the meandering of the rivers, and the rather limited width of the terraces, more than 600 acres are rarely found in a single tract. With the data now at hand it does not seem practicable to irrigate areas larger than this by pumping from a single fixed station. It

may be, however, that detailed study will show that two or more of these tracts may be connected by ditches and treated as one.

CANNONBALL RIVER FLATS.

Area and soil.—The elevation of the Cannonball flats varies from 10 to 80 feet. The soil is generally fertile, and at many points is well grassed. In places it appears to be gumbo, while at others it is too sandy for agriculture. Taken together these flats have a considerable area, perhaps 30,000 or more acres, with soil and topography favorable for irrigation. As on the Missouri, there are opportunities to form reservoirs on the tributary streams and divert the water so controlled to the flats of the larger stream. The difficulties here, as there, will be found in constructing at reasonable expense reservoirs sufficiently strong to bear the water put upon them by violent storms.

Lignite.—Lignite is not abundant on the Cannonball below Wade post-office, where the Cedar unites with it. Only the following outcrops were noted:

Three feet of coal, reported in Castle or Palace Butte, about 6 miles north of Cannonball post-office, at the mouth of the river. Samples examined were of fair quality.

A 14-inch bed, mined by stripping, about 18 miles from the mouth of the Cannonball, in sec. 21, T. 134, R. 81. The outcrop occurs close to the river.

A bed 2½ feet thick, reported in a bank 4 miles northwest of Shields post-office, and an equal distance from the river.

A bed 18 inches thick, reported 3 miles north of Howe post-office.

A careful search made along the bluffs where good exposures occur brought to light only beds a few inches thick, till the upper Cannonball was reached.

Forty miles east of New England post-office heavy lignite beds outcrop, and appear continuously from this point for 50 miles up the stream. The following may be briefly tabulated:

Lignite beds on upper Cannonball River, North Dakota.

	Feet.
O. S. Chase bank, sec. 31, T. 134, R. 92	2–3, good.
E. C. Barry, bank, sec. 4, T. 133, R. 92	3, good.
Sec. 21, T. 134, R. 94	3, good.
NW. ¼ sec. 22, T. 134, R. 94	3, good.
Secs. 21 and 22, T. 135, R. 96	4, good.
Jacob Reiss bank, sec. 22, T. 136, R. 97	7, good.
John Ermintrout bank, 6 miles northeast of New England	3
Two beds, 5 miles west of New England	9, good.

COALBANK CREEK.

Lignite.—Coalbank Creek, a tributary of the Cannonball, which unites with it near New England, shows good lignite beds frequently: one 4-foot bed may be found 4 miles from the mouth of the creek.

CEDAR RIVER.

Lignite.—On the upper Cedar River lignite is said to be abundant, and judging from observations on the adjacent tributaries of the Cannonball the reports are probably correct. The same statement can be made for the upper Grand River in South Dakota.

PRESENT STATUS OF IRRIGATION IN NORTH DAKOTA.

A great part of the irrigation in North Dakota is due to the stimulus given by the desert-land act. The application of this law in the State seems to have been free from abuse, and a further application of it has been prevented by the fact that extensive areas in the semi-arid portion of the State are not recognized as desert land by the land offices. The only part of the State where desert-land claims may be filed is the northwestern, and here there is always some uncertainty as to what the ruling of the land office will be till each claim is finally inspected.

FLATS PARTLY IRRIGATED.

YELLOWSTONE FLATS.

On the Yellowstone flat in North Dakota, and just over the line in Montana, the following claims have been filed:

Andrew F. Nohle: Reservoir on Fourmile Creek, a tributary of the Yellowstone in Montana, near the boundary line. Fourmile Creek is said to have a drainage area of 24 square miles. The Nohle dam when completed will be 20 feet high in the center, and the reservoir when filled will have a surface area of 388 acres.

A. W. Mann: Claim in SE. ¼ sec. 31, T. 152, R. 104. He purposes to obtain water from draws in the bluffs behind.

Sarah and Kate Mercer: Desert claims on NW. ¼ sec. 32, and NE. ¼ sec. 31, T. 152, R. 104. They obtain water from draws. The main ditch to control these areas is already constructed.

BUFORD-TRENTON FLATS.

On the Buford-Trenton flats Mr. Edwin Jack (post-office, Trenton) has been foremost in the effort to secure water for irrigation. Associated with him are Carl Wittmeier, Grant Conley, and Charles Schumaker. A dam on Eightmile Creek, which comes down from the

north and spreads out over the Missouri bottom lands 3 miles west of Trenton, has been constructed across the creek bed. The reservoir so formed has a surface area of 75.4 acres, and a capacity of 521.5 acre-feet. The dam, which is of earth faced with stone, has a suitable flume and waste gate. Its present capacity is regarded as sufficient, aided by the rainfall and inflow during the irrigating season, to care for 400 acres. The dam has washed out twice and has been rebuilt each time in a more substantial manner. Up to the present about $8,000 have been expended on reservoir and ditches, with results which have satisfied the owners that the outlay is justified. The capacity of this reservoir could be increased considerably without great expense, and it is probable that water from Eightmile Creek would still fill it if its capacity were not much above 1,000 acre-feet.

MUDDY RIVER FLATS.

The most notable attempt to irrigate in the vicinity of Williston was made a few years ago by Mr. Fred Rounsaville of that place. Ten miles above Williston, in sec. 5, T. 153, R. 100, he constructed a dam to divert the water from the stream and throw it into a lateral ditch, which would irrigate the flats on the right bank of the Muddy, and possibly a portion of the flats at its mouth on the Missouri. No attempt to store the water was included in the plan. The dam was constructed and a portion of the ditch, when the work was stopped by the death of Mr. Rounsaville. The property is now offered for sale.

On the Muddy above Williston and on its tributaries the following irrigation work is in progress, the operations for the most part being limited to spring flooding for grass:

George Marelius and Stephen A. Marmon have a reservoir in T. 151, R. 101, on Blacktail Creek, a tributary of the Muddy from the west. They are said to be flooding 1,200 acres for both grass and grain.

The Freeman family are constructing a reservoir on the upper course of the Muddy, in secs. 20, 23, 29, and 30, T. 158, R. 100, where they are planning to irrigate 1,900 acres.

Ellen Adams has a desert-land claim, which is now proved up, in secs. 28 and 29, T. 155, R. 98. Water is taken from coulees that are dry in summer, and the irrigation is for grass only.

Joseph Langford is irrigating 300 acres in secs. 21 and 27, T. 157, R. 100, on the upper Muddy.

F. R. Zahl and his family hold a section, which he irrigates for grass, in secs. 24 and 25, T. 159, R. 101, at the mouth of Scoria Creek, a tributary of the Muddy.

L. L. and Howard Lampman irrigate two sections on Cow Creek, a tributary of the Muddy, in T. 156, R. 102.

James Sherry, on Stump Creek, a tributary of the Muddy from the west, irrigates a 20-acre garden in sec. 2, T. 156, R. 102, by pumping from a reservoir in the creek. During the year 1903 he pumped only 4 days, this, with the rains, being enough to mature a full crop of garden truck. An 8-horsepower gasoline engine lifted 800 barrels an hour 20 feet. With gasoline at 30 cents a gallon, the cost of operation per day of 10 hours was $3. The owner estimates that with the rain of an ordinary year to assist, his plant is capable of irrigating 160 acres. The soil is a sandy loam with clay subsoil. The cost of pump, pipes, and engine delivered at Williston was $811. Mr. Sherry has great faith in the profit to be derived from the enterprise, and next year will extend the area that he irrigates.

Mr. E. A. Sharp, on his farm 2 miles northeast of Williston, in secs. 17 and 20, T. 154, R. 100, is installing a 10-horsepower gasoline engine and a centrifugal pump, which, for his lift of 10 feet, has a claimed capacity of 735 gallons a minute. He intends to irrigate for grass and grain. Water will be taken from Stony Creek and Muddy River. He estimates that he can irrigate 200 acres with his plant, and that 30 days will be a maximum time for operation in an ordinary year.

Joseph Langford has 320 acres in secs. 21 and 27, T. 157, R. 100, which he irrigates from the Muddy.

The Hedderick ranch (formerly the Voss) irrigates extensively for grass at the mouth of Cow Creek, on the Muddy flats.

R. M. Calderwood, Grant Greenup, Francis Hendrickson, and others have filed desert-land claims on Camp Creek, in T. 151, R. 102, and have made preparations to irrigate extensively.

LITTLE KNIFE FLATS.

Mr. Black has irrigated with profit for grass at the mouth of Little Knife Creek for a number of years.

NESSON-HOFFLUND FLATS.

The Nelson ranch, at the mouth of Nelson Creek, on the upper terrace at that point, is an illustration of the possibility of irrigating like land at a moderate cost from the creeks coming down from the upland. An earth dam at the mouth of Nelson Creek diverts the water and laterals spread it over a considerable area so that 600 acres or more are flooded in the spring. The ground is thoroughly soaked to a depth of 2 feet and is then allowed to stand a week before cultivation. On land so prepared oats often yield 60 bushels to the acre and wheat 25, while the surrounding country, as favorably located except for the flooding, yields from nothing to 10 bushels.

One of the earliest attempts at irrigation in North Dakota was made at the old Grinnell ranch, at the mouth of Beaver Creek, where by dams and ditches the water from the creek was spread over several hundred acres of the lower Hofflund flat. Part of the same area is irrigated in the same way by H. A. Carey. Carey's dam is 20 feet high and is not intended to store water in the creek bed back of it to any considerable extent but to divert it to the laterals during the abundant water supply of the spring.

Ole Barsted has a dam and ditch on Dry Fork Creek, near its junction with the Beaver. Higher up on this creek are the dams of Wallender and Manly Anderson.

Nels J. Camp, William Barsted, and George Littlefield are diverting water for irrigation on Beaver Creek above Carey's.

Ward is irrigating the east end of the lower flat at Hofflund, at the old Lampman ranch.

HANCOCK FLATS.

Mr. F. G. Mattoon is putting in an extensive pumping plant to irrigate a portion of the fine flats on the Missouri at Hancock.

HEART RIVER FLATS.

Fisher Brothers, on Green River, a small tributary of the Heart, 7 miles north of Dickinson, have irrigated for two years, pumping water from the river. The lift is 15 feet, and a centrifugal pump with a discharge pipe having an inside diameter of 8 inches is used. A temporary dam 10 inches high and 30 feet long was thrown across the river in 1901 and retained all the water needed to irrigate 40 acres. In 1902 an abundance of rain made irrigation unnecessary. With this pump, which is driven by an ordinary farm engine, 1,500 gallons per minute are easily raised 15 feet. The cost of the pump delivered was $250. Mr. Fisher estimates that even in a dry season he would have no difficulty in irrigating 200 acres with his present equipment. Two dollars worth of coal was burned per day, coal costing 50 cents per ton at a neighboring bank.

Mr. A. F. Riley, on Heart River, near Gladstone, last year irrigated 20 acres by means of a dam thrown across a draw. Next year he proposes to irrigate 60 acres by means of a centrifugal pump. Lignite occurs on his farm, outcropping in a 4-foot seam, and can be had for the mere labor of mining.

RECOMMENDATIONS.

Opportunities to reclaim arid lands appear to exist in the larger flats on Missouri River. Much of the land in these flats is, however,

already in private ownership, that lying within the Fort Berthold Reservation forming the only exception.

In choosing among the Missouri River flats for one where reclamation by pumping may be tried under most favorable conditions, a number of factors must be kept in mind. Nearness to a railroad and a market are as essential as an abundance of cheap fuel and good land. An active interest on the part of the resident owners is necessary where the land is already in part or wholly private property.

With these conditions in mind, the Buford-Trenton flats and the Nesson-Hofflund tract deserve first consideration. The former lie directly on the railroad, but lignite is not abundant near by and will cost about $2 per ton, whether mined in the vicinity or hauled from Williston. The Nesson-Hofflund flats are 14 miles from a railroad and are wholly in private ownership, but, on the other hand, lignite is very abundant near them and should be laid down at the pumping plant for $1 per ton; it may even be possible to locate a pumping plant within a few hundred yards of an extensive outcrop. From an engineering point of view, the Buford-Trenton tract appears so offer simpler conditions.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGY AND WATER RESOURCES

OF

A PORTION OF EAST-CENTRAL WASHINGTON

BY

FRANK C. CALKINS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., June 18, 1904.

SIR: I have the honor to transmit herewith, for publication in the series of Water-Supply and Irrigation Papers, a report by Mr. Frank C. Calkins on the water resources of a portion of east-central Washington, made in connection with the investigation of the underground waters of the Western States, under charge of Mr. N. H. Darton.

The information contained in this paper is believed to be of value as a help to the understanding of the underground waters of that portion of the country.

Very respectfully, F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

GEOLOGY AND WATER RESOURCES OF A PORTION OF EAST-CENTRAL WASHINGTON.

By Frank C. Calkins.

INTRODUCTION.

During the fall of 1902 the writer, acting under instructions from Mr. F. H. Newell, chief engineer, United States Geological Survey, made an examination of the water resources of a portion of east-central Washington. The location and extent of the district investigated are shown on the index map, fig. 1.

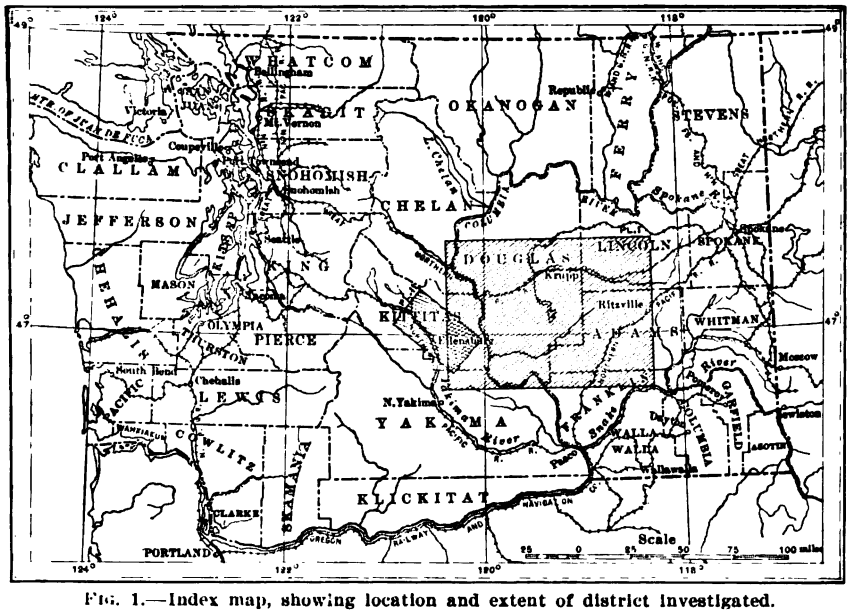


Fig. 1.—Index map, showing location and extent of district investigated.

The objects of the investigation were determined by the natural conditions of the region. The climate of central Washington is arid, and a large portion of the district here especially considered is almost without surface streams available for the uses of mankind. Surface wells capable of supplying perennially even the modest requirements of domestic use can be sunk only in places where conditions are locally favorable. Springs once formed the only source of water for

a large area, but they are so widely scattered and often so difficult of access that great labor is sometimes involved in hauling a supply from them. Deep wells, now fairly numerous and rapidly increasing in number, are coming to be considered the most satisfactory source of water. To determine to what extent the supply from these wells may be increased, and to find whether there is hope of obtaining artesian flows in any portion of the region, were the prime objects of the writer's expedition.

Geologic reconnaissance was carried on at the same time, as a knowledge of the character of the rocks and of their geologic structure is necessary to an intelligent opinion in regard to the possibility of obtaining underground water. A sketch of the geology of the region will, therefore, be incorporated in this report. It is limited on the one hand by the economic purposes which it is meant to serve and by the fact that it is intended primarily for nonscientific readers, and on the other by the hasty character of the work and the lack of a good topographic base, which made impossible a complete geologic survey of the region. The routes indicated on Pl. I show the ground covered and will enable the reader to judge to what extent the opinions expressed are based on actual observation.

Field work was carried on during the four weeks beginning October 6, 1902. The equipment consisted of a spring wagon and team, a saddle horse, used in occasional excursions from the main routes, and a light camp outfit. Mr. D. F. McDonald, a student at the University of Washington, was engaged as teamster, and his intelligent interest in the work enabled him to assist materially in the collection of data.

Mention should be made here of geologic and hydrographic work previously done in this region and in neighboring areas where conditions are similar. Among the earliest scientific explorations in the region whose results have been published were those of Thomas W. Symons, who, in the fall of 1881, explored the Columbia from Grand Rapids to the mouth of Snake River. His report[a] includes a description of the Great Plains of the Columbia and a sketch of the geologic history of the region. The most extensive and important work in the Columbia Plains has been done by Prof. Israel C. Russell, the results of whose investigations in central Washington,[b] southeastern Washington,[c] and northwestern Idaho[d] have appeared in publications of the United States Geological Survey.

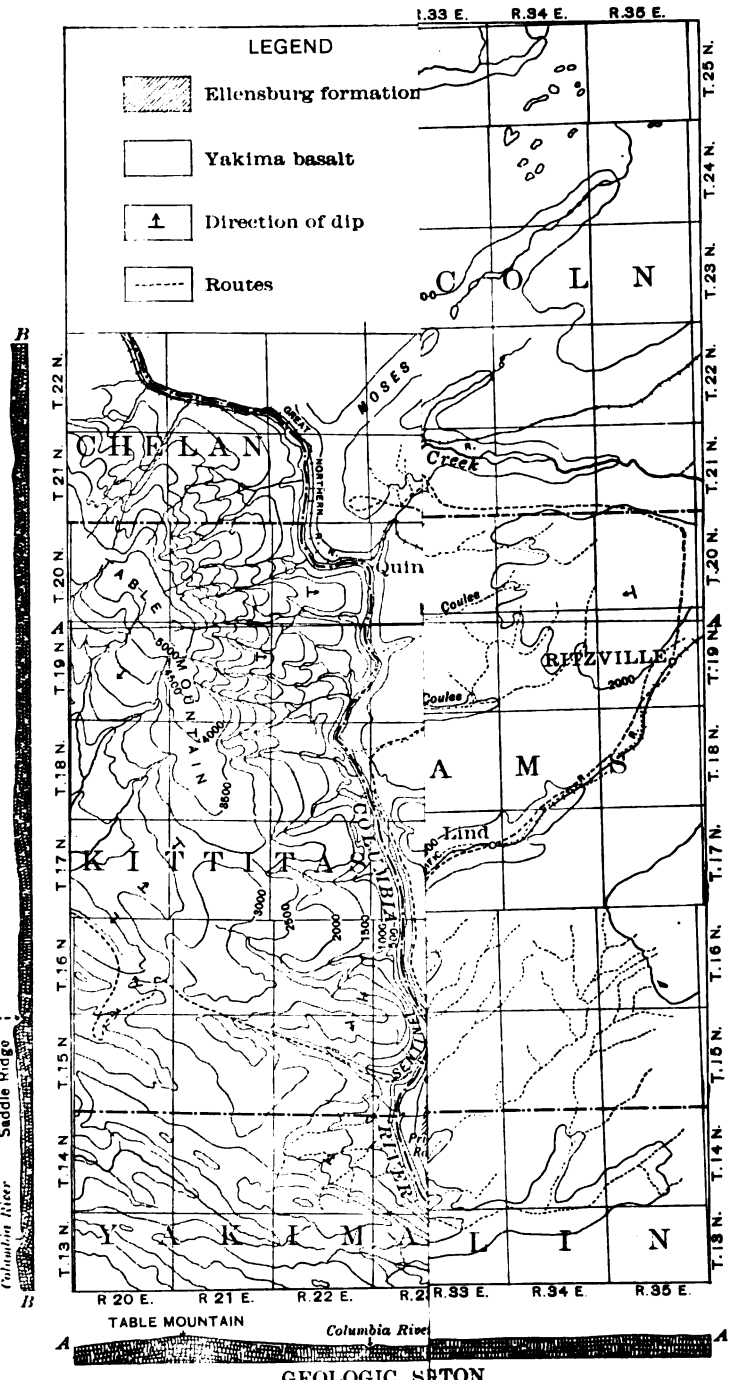
---

[a] Report of an examination of the upper Columbia River: Forty-seventh Cong., 1st sess., S. Doc. No. 186, 1882.

[b] Russell, I. C., Geologic reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893.

[c] Russell, I. C., Reconnaissance in southeastern Washington: Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, 1897.

[d] Russell, I. C., Geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Papers Nos. 53 and 54, U. S. Geol. Survey, 1901.



GEOLOGIC SECTION

TOPOGRAPHY COMPILED C. CALKINS

Professor Russell's first work in the region was a reconnaissance in 1893, which embraced a large area in central Washington, including the greater part of the district considered in the present report. The conclusions in regard to certain geologic problems reached by the writer after a more thorough examination of the ground differ in some particulars from those of Professor Russell, but they can not claim the authority of final solutions, which must depend on more detailed studies. It is a pleasure, however, to acknowledge indebtedness to Professor Russell for many helpful suggestions contained in his reports.

The water resources of a portion of Yakima County were studied in 1900 by Mr. George Otis Smith.[a] His report is of especial interest because it describes the most successful artesian basin in the State and because his data were based largely on detailed areal work in the Ellensburg quadrangle. The Ellensburg folio,[b] which has recently been published, affords a detailed description of a region where the geologic conditions are similar to those of a part of the area described in the following pages.

The writer's acknowledgments are due to Mr. F. H. Newell and to Mr. George Otis Smith for suggestions and criticisms in regard to the preparation of this report. For assistance in the collection of well data he is indebted to a great number of drillers, ranchers, and others, to mention all of whom by name would require too much space, but to whom he expresses thanks collectively. He would, however, express especial obligations to Mr. Ralph Kauffman, of Ellensburg, who furnished a large part of the information concerning the water resources of Kittitas Valley.

GEOGRAPHY.

TOPOGRAPHY.

MAIN TOPOGRAPHIC DIVISIONS OF EASTERN WASHINGTON.

The most important topographic feature of Washington is the Cascade Range. This noble chain of mountains, beginning in northern California, extends north through Oregon and Washington, but in the neighborhood of the forty-ninth parallel it loses its mountainous elevation and ruggedness and merges into a deeply dissected but distinctly lower plateau. The average elevation of the Cascade summits is between 6,000 and 7,000 feet, and though comparatively few peaks rise above the latter height, a large number are more than 6,000 feet high. A few great extinct volcanoes, such as the well-known cones of Rainier, Adams, and St. Helens, covered with eternal snows, tower to double the height of the rest.

---

[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Wash.: Water-Sup. and Irr. Paper No. 55, U. S. Geol. Survey, 1901.

[b] Ellensburg quadrangle: Geologic Atlas U. S., folio 86, U. S. Geol. Survey, 1903.

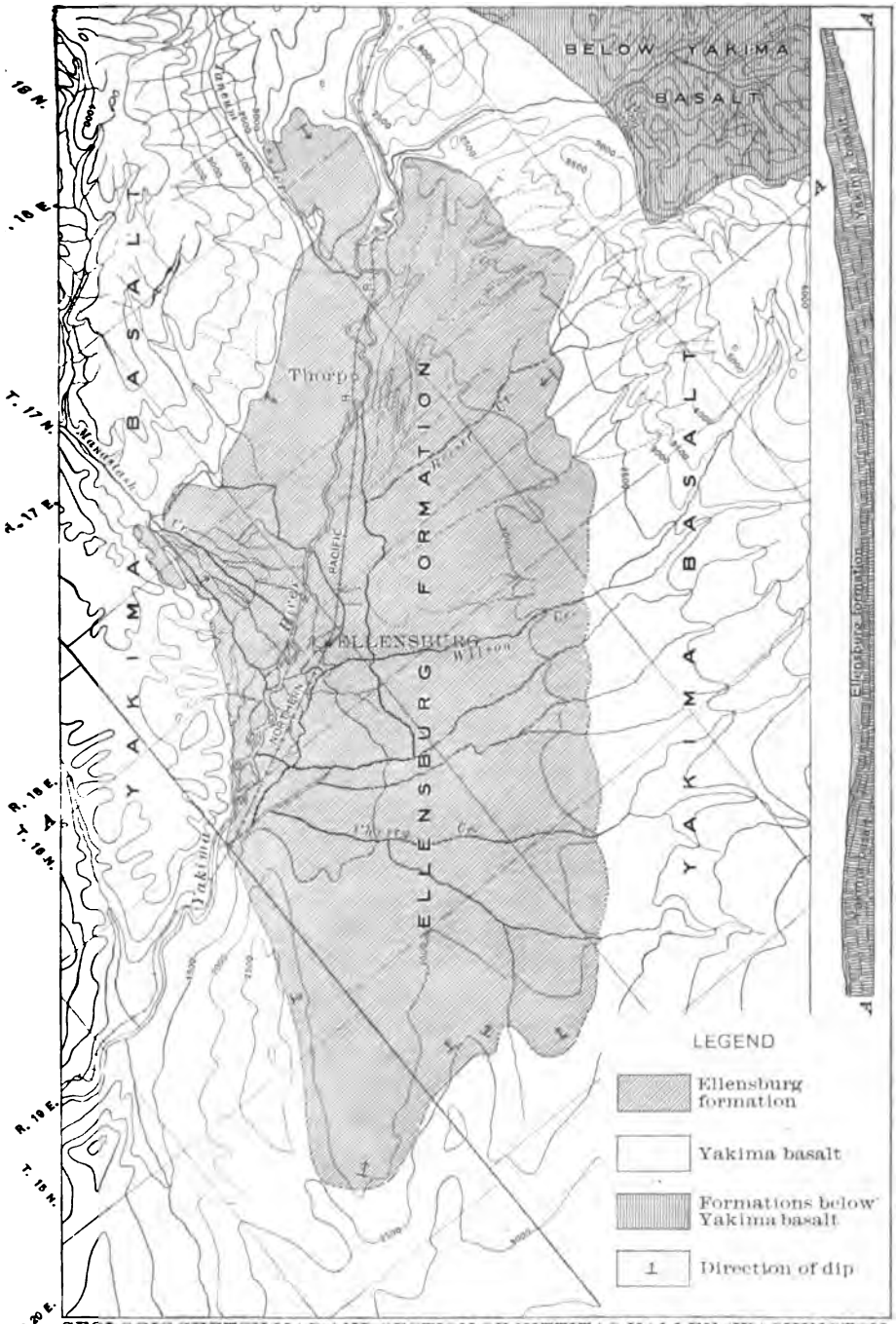
The region east of the Cascade Mountains, in which the area considered in this report is embraced, lies for the most part in that broad topographic province known as the Great Plains of the Columbia. This province may be roughly defined as follows: On the south and southeast its boundary is somewhat irregularly marked by the Blue Mountains of Oregon and Idaho, on the east by the Bitterroot and Cœur d'Alène ranges, on the north by a mountainous though not extremely rugged region comprising the Okanogan highlands and the Colville Mountains, and on the west by the Cascade Mountains, which merge into these highlands.

The extensive area thus outlined is by no means a plain in the strict sense of the word; between its lowest and highest points there is a difference in altitude of 4,000 feet. It includes great plateau-like areas in its eastern and northern portions and broad stretches of low-lying sandy waste along the Columbia in southern Washington and northern Oregon. The level expanses are broken, moreover, by hills and ridges, usually of rather gently rounded profile, and the high plateau-like portions are trenched by streams that have formed magnificent steep-walled canyons. But to the traveler upon the broad stretches between the streams the canyons are not visible until he reaches the brink, and the hills and ridges, not rising in general to great heights, are of little importance in comparison with the vast intermediate areas, level or but gently sloping. Thus the inequalities of the surface, while relieving the monotony of the landscape, do not determine its character, nor make its designation as a great plain seem inappropriate to one familiar with the region.

As the western border of the Columbia Plains crosses the area with which this report is especially concerned it will be necessary to make some further statement in regard to its character and its relations to the Cascade Mountains.

The boundary between the Cascade Mountains and the plains varies in sharpness of definition. North of Wenatchee the division is very accurately marked by Columbia River. West of the profound canyon of this river the country is rugged and thoroughly dissected by streams that are generally separated by sharp, or at least narrow, divides. On the east the rim of the canyon is the edge of a plateau standing about 2,000 feet above the river, and although Badger Mountain rises rather prominently above its general level, and its border is notched by canyons tributary to the Columbia, it has the general topographic character of the Columbia Plains.

South from Wenatchee to Sentinel Bluffs the plains are overlooked on the west by Table Mountain, which rises with a somewhat gentle slope from the brink of the river gorge to a broad summit over 5,000 feet above the level of the sea. South of Table Mountain, however, the boundary between the mountains and the plains becomes less



GEOLOGIC SKETCH MAP AND SECTION OF KITTITAS VALLEY, WASHINGTON

TOPOGRAPHY BY U. S. GEOLOGICAL SURVEY AND NORTHERN TRANSCONTINENTAL SURVEY

GEOLOGY COMPILED FROM U. S. GEOLOGICAL SURVEY SHEETS AND FIELD OBSERVATIONS BY F. C. CALKINS

1904

Scale

2 0 2 4 6 8 10 miles

Contour interval 500 feet

definite, and there intervenes a region intermediate, not only in position but in topographic character, between the two great provinces in their typical aspects.

This border region is characterized by the presence of many well-defined ridges, whose trend varies from east-west to northwest-southwest, and whose even crests rise gently toward the west and merge with the Cascade Mountains proper, while to the east they gradually sink and are lost on the surface of the plains. Between these foothill ridges there are broad valleys which, by the aid of irrigation, have become the richest farming lands of eastern Washington; the aggregate area of these valleys, however, is barely equal to that of the distinctly hilly lands. To a traveler in the valleys the landscape presents an aspect very similar to that of the Columbia Plains, the resemblance being heightened by the fact that the character of the natural vegetation is similar in the two regions. The hills in the landscape, however, give it a certain degree of contrast with the more monotonous scenery of the plains. This borderland between the plains and the mountains, therefore, while not very distinctly marked off from either, is sufficiently well characterized to deserve recognition as a topographic province. It might appropriately be called the foothill region.

TOPOGRAPHIC DETAILS.

KITTITAS VALLEY.

The region considered in this report includes a portion of the foothill region, but lies mainly in the Columbia Plains.

Kittitas Valley (see Pl. II), which forms the westernmost portion of the area, is the northernmost of the large foothill valleys. The broad floor of this basin-like depression contains an immense area of fertile farm land. Its configuration is favorable to irrigation from Yakima River and from its numerous small tributaries that flow from the mountains west and north, for there is everywhere a gentle slope toward the principal stream. Yakima River, however, does not flow through the valley from end to end, but only traverses its western portion diagonally and makes an abrupt exit through a profound gorge. The southeastern continuation of the basin is without perennial streams, and since it has a somewhat steeper gradient than the western portion, a large part of it can not be irrigated from the highest ditch now taking water from the river.

The flat lands of Kittitas Valley are separated by a considerable stretch of hills from the Columbia Plains.

THE DESERT.

That portion of the plains lying just east of the Columbia has a desolate, almost desert-like aspect, and will for the sake of brevity

be referred to as "the desert." The greater portion of it is nearly level, but its monotony is relieved by two east-west ridges, the most prominent of which is known as Saddle Mountain. This straight and simple ridge extends to a point about 40 miles east of the river, where it sinks gradually to the level of the plain. It is, in fact, an offshoot from the larger Table Mountain uplift, from which it has been cut away by the Columbia. The basalt cliffs known as Sentinel Bluffs, forming the portals of the gate which the river has made through the ridge, are among the grandest scenic features of the region. Saddle Mountain has a fairly gentle southern slope, but its northern face is strikingly abrupt, being for some miles east of the river a precipitous cliff more than a thousand feet high. Farther to the east this cliff gives way to a rather steep slope.

The surface of the desert is covered with a dry sandy soil, which is constantly shifted by the winds, although its motion is somewhat retarded by a scanty growth of shrubs and grass. The character of the soil and climate and the absence of surface water are conditions that have prevented attempts at cultivation, except along Columbia River and Crab Creek, though the northern border of the district is dotted with the cabins of a few homesteaders. The greater portion of the desert is given over to grazing and is without human habitation.

THE WHEAT LANDS.

Embracing the desert-like area on the north and east is the more elevated portion of the Great Plains of the Columbia, which extend northward into the so-called Big Bend of the Columbia and eastward into Idaho. The topographic character of the part south of upper Crab Creek is that of a plateau dissected by canyons. North of Crab Creek there is a ridge, whose cross profile is that of a broad, flat arch forming the south side of a valley with gently sloping sides. The two last-mentioned features are terminated to the west by the Grand Coulee, beyond which rises an elevation, plateau-like in character, but considerably ravined and with no very broad level areas.

These plateau-like portions of the Columbia Plains are fitted by natural conditions to wheat growing, and have a considerable and an increasing farming population. They will be referred to generally in the following pages as the "wheat lands."

DRAINAGE.

Columbia River.—The master stream of the region is the Columbia. Despite its great volume, this river contributes little to the economic resources of east-central Washington. It has several rapids in its course through the region, among them being Priest Rapids, which can not be ascended by steamers except with great danger and

difficulty. These rapids extend for about 7 miles and consist of 7 "ripples;" at the foot of the last one the river is deflected by a ridge having a bold cliff for its northern face, along which it flows for several miles. The fatal obstacle to the use of the Columbia waters for irrigation lies in the fact that the stream flows in a canyon with fairly abrupt walls, sunk from 300 to 1,000 feet below the broad, flat stretches to the east, and that its gradient, though fairly high considering the volume of its flow, is much lower than that of the rivers in the foothill region, so extensively used for irrigation.

Crab Creek.—The large area of the Columbia Plains embraced in the great sweep of the river, bounded on the north and west by the Columbia, on the south by Snake River, and on the east by the one hundred and eighteenth meridian, has only very insignificant surface streams, the only one that maintains a perennial flow along the greater portion of its channel being Crab Creek, which rises in the vicinity of Davenport, Wash., at an elevation of about 2,500 feet. Its total length, neglecting minor curves and including the lakes in its course and the stretches where it flows beneath the alluvium in the bottom of its canyon, is about 250 miles, about the same as that of Yakima River. Its course through this region is readily divisible into three parts. The first and longest of these, in which the general direction of the stream is nearly from east to west, may be designated upper Crab Creek. The surface flow is perennial along the greater part of this stretch, though at the time of the writer's visit the channel was dry from an unknown distance above Odessa to a point about 3 miles below, where the stream emerges from the gravels in considerable volume. It sinks again below Wilson Creek, to rise near the head of Moses Lake, which probably owes its existence to the formation of a range of sand dunes across the ancient channel of the creek. The dam thus formed, however, is a leaky one, and the waters seep through, to gather below, forming a stream perhaps slightly diminished from its former volume by evaporation in the lake. This southward-flowing portion of the stream may be designated middle Crab Creek. About 15 miles below the lake the stream again takes a westerly direction, flowing in a broad-bottomed, steep-walled canyon. At some point near the middle of this lower course Crab Creek sinks finally, and delivers no surface water to the Columbia at the mouth of its canyon. This west-flowing section of the stream may be designated lower Crab Creek.

Coulees.—Crab Creek has only a few branches that contribute to its surface flow throughout the year and a few more that flow during the rainy season, but it has a great number of tributary canyons which are perfectly dry except at periods of unusually heavy rainfall. Many of these are scores of miles in length and of corresponding width and

depth. These canyons, dry or containing only small streams disproportionate to their size, are known as coulees. They have all the topographic characters of stream-carved valleys, but it is evident that they could not have been formed by stream erosion under present conditions. Their origin must be referred to a prehistoric period in which the region had an abundant rainfall and was well watered by surface streams. These branching systems of dry canyons represent ancient river systems.

The most important of the branches of the ancient Crab Creek system, except Grand Coulee, whose peculiar history separates it from the others, is Lind Coulee, in which the Northern Pacific Railway runs from Providence to Ritzville.

Providence Coulee, in which Hatton, Scott, and Connell are situated, is now devoid of flowing water, though it once formed the trunk of a river system almost as considerable as that for which Crab Creek is the master stream.

Of all the abandoned canyons of the Columbia Plains, however, the greatest and most remarkable is Grand Coulee. Not only does it possess many features of scenic grandeur, but its geologic history is of the highest interest. This great chasm was carved by Columbia River at a time when its profound gorge was dammed by a great ice lobe that came down the valley of the Okanogan and pushed southward some 30 miles across the plateau south of the master stream. The waters of the Columbia, deflected by the great glacier, flowed along its eastern face, and, continuing southward in what is now the bed of Crab Creek, regained their proper channel just above Sentinel Bluffs.

Opening from the canyon of the Columbia near the northwest corner of Lincoln County, the Grand Coulee extends in a southwesterly direction for over 30 miles. Throughout the greater portion of this distance it is a wide, flat-bottomed canyon, walled by cliffs, but a little south of its middle point its western wall subsides and it is joined by a broad valley with gently sloping sides. Opposite the mouth of this valley a plateau rises nearly a thousand feet above the bottom of the coulee, but the ascent to this upland is made on a moderate slope unbroken by cliffs. This break in the walls of the chasm, constituting the only point where the Grand Coulee proper can be crossed by a wagon, has determined the location of the small town known as Coulee City. Above this middle pass the coulee bottom, partly covered by alkaline lakes and playas, is about 1½ miles wide, with basalt cliffs which rise on either side to a height of about 400 feet. Two miles below the town the bottom of the canyon abruptly drops, and two amphitheaters, separated by a narrow point and walled by vertical cliffs 400 feet in height, mark the place where the Columbia once poured in a mighty cataract.

The gorge extends southward 15 miles farther. The eastern wall of this lower section does not rise much higher than the level of Coulee City, but its western side maintains a commanding elevation and forms a frowning escarpment visible for many leagues to the south and east. The coulee finally opens out in the northeastern portion of the desert upon a gravel plain, the surface being higher than that of Soap Lake, the southernmost of the chain that lies in the deep chasm. Beneath the mantle of surface material, however, the rocky channel probably persists, and is continued in the depression occupied by Moses Lake and Crab Creek.

Lakes.—Lakes, generally shallow and of small extent, are very numerous in the northern portion of the region. They are invariably situated in coulees, their basins having been formed by the erosion of former streams or dammed by wind-blown materials. They are, therefore, usually elongated in form and separated by stretches of dry or meadowy land; often they are disposed in chains. The most important series in this region is that which lies in the bottom of the Grand Coulee. In this chain we may include Moses Lake, the largest sheet of water in the Columbia Plains.

The majority of the lakes in this arid region have no outlets, while others overflow only in the rainy season. As a consequence, the small amounts of salts contained in all surface waters are concentrated in the lake basins by evaporation, and a majority of the lakes are more or less alkaline, Moses Lake containing about 0.32 gram of total solids per liter of water.[a]

The lakes in the lower section of the Grand Coulee are successively higher from south to north, and the northern lakes occasionally overflow to the south at seasons of high water. It follows that, while the water of the northernmost of these lakes is comparatively fresh and palatable, the waters of the others become successively more alkaline to the south. Soap Lake, the most southerly, is extremely alkaline; its waters when they lap against the shores on windy days are beaten into great masses of white foam like soap suds. The alkalinity of the lake is further shown by the soapy feeling observed on rubbing the hands in its water and by its bitter taste, so strong and disagreeable that it is refused by a thirsty horse accustomed to more palatable water. The cattle of the neighborhood, however, constrained by necessity, have overcome this natural repugnance and the lake is a drinking place for a large number of them.

Soap Lake contains 28 parts in 1,000 of matter in solution, consisting essentially of carbonates, sulphates, chlorides, and bicarbonate of soda.[b]

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[a] Ann. Rept. Geol. Survey of Washington, vol. 1, 1901, p. 294. [b] Ibid., p. 295.

Sulphur Lake, in Washtucna Coulee, is another pond in which the water is an extremely concentrated alkaline solution.

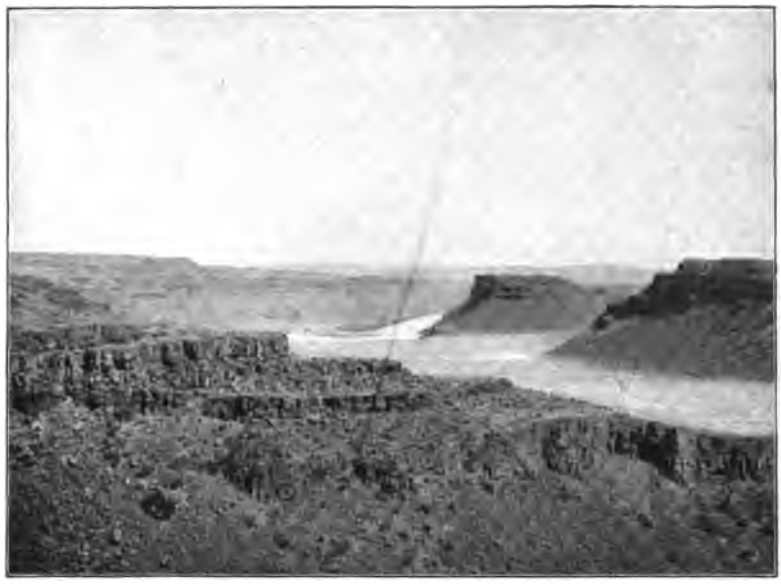
In this connection should be mentioned the numerous "alkali flats" or playas, which are ponds during a portion of the year, but become dry every summer, and which have their supply of salts annually increased by the amount held in solution by the waters that flow into them during the rainy season.

A typical coulee, containing small lakes, is shown on Pl. III, *A*.

CLIMATE.

The most characteristic climatic features of eastern Washington are due to the fact that the region is separated from the ocean by a broad belt of fairly high mountains. The great influence of the Cascade Range is rendered manifest by the sharp contrast that obtains between the climates of eastern and western Washington. The region on the seaward side of these mountains has a climate that is remarkably mild, considering the rather high northern latitude, and that is without extremes of heat or cold. The most characteristic feature, however, is its extreme humidity. The eastern part of the State, on the contrary, being removed from the tempering influence of the ocean and the warm Japan Current, which flows along the north Pacific coast, has the wide range of temperature that is characteristic of the climate of interior regions. The winds of the Pacific, which supply the abundant rainfall of the Sound country, can not cross the broad Cascade Range without losing the greater portion of their moisture by condensation in the form of rain or snow, and the climate of eastern Washington is therefore as decidedly arid as that of western Washington is humid.

The average yearly rainfall in Kittitas Valley, as deduced from Weather Bureau statistics covering many years, is approximately 8 inches. For other localities in the area with which we are directly concerned there are only the most fragmentary records. At Lind, in the wheat lands, the observations for 1898 and 1899 show a total for each year of about 12 inches. Incomplete records at Ritzville during the same years apparently indicate an annual average about equal to or slightly less than that of Ellensburg. At Coulee City the scanty data indicate an annual rainfall not far different from that of Ritzville. At Connell, in the southeast quarter of the area considered, the precipitation in 1900 was 2.29 inches for all of the year except April and November; in 1899, 2.24 for all except January, February, and March. These figures indicate that the mean precipitation at that locality is extremely low, probably not above 5 inches per annum. Although figures are lacking for what has been termed the desert, its general aspect indicates that its annual rainfall probably does not average more than that of the vicinity of Connell.



A. TYPICAL COULEE SOUTH OF COULEE CITY.

B. COLUMNAR PARTING IN BASALT, UMPTANUM VALLEY.

The seasonal distribution of the precipitation is very characteristic; as in all the far West, there is a wet season and a dry season. By far the greater portion of the annual supply of rain and snow falls between October 1 and May 31. The precipitation is for the most part in the form of gentle rain, which is generally almost entirely absorbed without considerable loss by run-off. The amount of snowfall in winter is often fairly large, however, and the drifts are often sufficiently deep on the hills to obstruct travel from Kittitas Valley to the Columbia.

The mean annual temperature at Ellensburg is approximately 48°. For localities in that portion of the area considered which lies in the Columbia Plains very scanty records are available. In 1899, when the annual average for Ellensburg was 46.5°, that for Lind was 50.2°. It may be safely asserted that the average temperature for the eastern part of the area is slightly above that for Kittitas Valley, and probably not far from 50°. The range of temperature, as mentioned before, is high, the greatest variation noted being in the Weather Bureau record for Lind during 1899, when the maximum was 112° and the minimum —33°. The temperature at Ellensburg, however, generally keeps within the limits +96° and —15°, while in the lower portions of the Columbia Plains both limits are somewhat higher. The figures giving the dates between the last killing frost in spring and the first in autumn are of considerable interest to students of agricultural conditions. The last spring frost usually occurs in the latter part of May, but has been known to be deferred until early in June. The first severe frost of autumn usually falls near October 1, but occurred at Ellensburg on September 9 in the unusually severe year of 1895. The lateness of spring frosts is inimical to the culture of such fruits as peaches, cherries, and apricots.

VEGETATION.

The natural vegetation of central Washington is chiefly influenced in its broad variations by climatic conditions. The only great forested area in the region here considered is on Table Mountain, whose height gives it a much moister and cooler climate than that of most of the region. The Columbia Plains and the comparatively low foothills are almost treeless, though Yakima River and certain small streams are bordered with a more or less considerable growth of trees and shrubbery. The treeless regions are clothed with a scanty vegetation composed of hardy grasses and shrubs, whose general aspect would be familiar to anyone acquainted with the arid regions of the West. In addition to the important influences of climate and water supply, soil conditions cause more local and less conspicuous variations in the flora.

The forest that clothes the top of Table Mountain comprises many species of fir, spruce, pine, and tamarack. In the sparse growth of its lower slopes the prevailing species is the yellow pine. The woody growth that borders the Yakima includes many large trees, mainly cottonwood and alder, with a sprinkling of yellow pine and a dense undergrowth of willows and other shrubbery. East of Kittitas Valley there are few plants worthy to be called trees. The small streams and springs are fringed with a more or less scattered growth of willow, birch, and wild cherry. The Columbia's banks are destitute of trees except for a few small junipers growing on its flood plain.

On the Columbia Plains and the southeastern foothills, almost desert-like in their aspect, the characteristic species are sagebrush and bunch grass, occurring in variable proportions. Sagebrush is moderately plentiful in all the western part of the region exclusive of the forested areas, attaining perhaps its greatest size and abundance in the central portion, near the boundary between the desert and the wheat lands. Eastward it diminishes, growing rather sparsely about Connell, Ritzville, and the other towns along the Northern Pacific Railroad. Bunch grass was seen in greatest luxuriance where the sagebrush is least abundant, but as it had there been protected for some years by fencing, it is difficult to say where it grew thickest before the land was swept by grazing herds.

The local variations of flora, determined by the character of the soils, are of considerable interest. In the sandy western portions of the plains, for example, while the general aspect is similar to that of the typical sagebrush land, the shrubs are mainly of species other than the true sage, and the true bunch grass is replaced by species more adapted to survive in this very dry soil. In the coulee bottoms other peculiar conditions have an equally decided influence on vegetation. The borders of the fresh-water ponds support a growth of tules. The meadow lands are covered with wild grasses, the short stiff-bladed salt grass being characteristic of the more alkaline soil. In soil that is alkaline but dry rye grass and greasewood, or thorny sage, form the principal growth. The character of the vegetation thus affords an index of the agricultural properties of the soil.

GRAZING.

The early settlers found eastern Washington a rich grazing region. The natural growth of nutritious bunch grass was so abundant that winter feeding often could be dispensed with and cattle and horses wintered on the open range, though there was doubtless great hardship and frequent death from cold in the more inclement winters. In the eastern portion, however, there was always the great drawback common to so many of the western ranges, of scanty water supply.

and during the hot months the necessity of keeping within a moderate distance of water prevented the stock from availing themselves of the entire grazing area.

Since the early days, however, the ranges of east Washington have greatly deteriorated. In this, as in most other western grazing regions, the forage plants have been eaten down so constantly that the forces of growth have been unable to compensate for the continual loss, and the evils of overgrazing have conspired with the encroachment of other agricultural industries to cause a decline in the extent and profitableness of the stock business. In consequence of the last-named cause the areas devoted to open grazing have been reduced to include only the lands unfitted by their topography, the nature of their soil, or the insufficiency of their water for the growth of hay, grain, and other crops.

The most important of the areas still devoted to grazing are the hills and the desert.

The rolling hills in the southwest part of the region and the slopes of Table Mountain constitute a large and important stock range. They have few level tracts extensive enough for economical cultivation, and the soil is generally thin and interrupted by patches of barren rock. In a state of nature the hills were abundantly clothed with bunch grass, and still afford excellent pasture where excessive grazing has not occurred. Springs and rivulets, though not abundant, are plentiful enough to render the greater part of the grass available to the stock.

The second great stock range is coextensive with what we have termed the desert, where the sandy character of the soil, combined with great aridity of climate, seems to forbid the hope of dry farming, and where there is no water for irrigation. Watering places are here few and far between. In the northeast quarter the grazing animals resort principally to Moses Lake; farther south, and near the eastern limit of the range, to Skuten Springs; in the central portion of the desert, to lower and middle Crab Creek; and along the south and west edges, for the most part, to Columbia River, although in the northwestern portion, where the stream is bordered by lofty basalt cliffs, they resort in part to springs. The dispersion of drinking places, as an inspection of the map will show, is so great that there are spots that lie many miles from any surface water.

The effects of excessive grazing are first felt in the areas near springs and streams, a fact strikingly evident to every traveler in this desert-like region. Along the borders of the streams there are broad stretches, often many miles across, where the bunch grass has been eaten down to nearly complete extermination. Farther back

from water the grass is much less closely cropped, and there are areas that seem to lie almost untouched from year to year.

There is another way in which the hard conditions of life on the range are forced upon the attention of the traveler. He will soon notice that the plain is traversed by numberless straight, deep-worn trails, and further observation will show that they are arranged in systems, converging toward points on the borders of a stream canyon or of some coulee in whose depths there is a spring or lake. Following a trail in the direction of water, he will find the minor paths gathering together as do the branches of a river system, to unite finally in a broad, well-beaten track that passes down some gully affording a graded route to the drinking place. A thirsty animal at any point in the arid range, by merely falling into the nearest trail and following it to the end, may generally make his way to water by the shortest possible route. A frequent and impressive sight is that of a band of horses on the way to a drinking place, following a trail in single file and moving at a swinging trot or easy lope in order to consume a minimum of time in the necessary quest for the refreshing element. In the dry season this journey must be made daily, but in the other months, when the demands of nature are less and are partly supplied by snow and the rain absorbed by the dry grass, the stock may abstain from drinking for several days at a time.

Since the horse can cover more ground and can afford the time to make longer journeys to water, the excessive restriction of the range has been more prejudicial to cattle than to horses, and horses have therefore become much more numerous than cattle upon the open range.

Two minor classes of range land remain to be noticed. The first comprises the slopes bordering the coulees of the wheat lands. Broken by terraces and by outcrops of basalt, they are unsuited for grain culture, but bear a considerable growth of bunch grass. In the aggregate these lands constitute a large area adapted for grazing, and one that probably never can be available for any other use.

The second class comprises certain narrow strips lying along rivers and lakes and watered by their underflow or seepage. The gravelly flood plain of the Columbia supports in places a scanty growth of lupine and other weeds that are eaten by cattle. The horses prefer to range back where the forage, though less palatable than this verdant growth, can be gathered more rapidly, and thus the green fodder is left to the sluggish cattle. More important, however, are the natural meadows that border Crab Creek and some of its tributaries, with certain of the desert lakes. These meadows are covered with abundant grass, and the generous growth has led to their being appropriated, fenced off, and used for pasturing and hay growing.

AGRICULTURE.

GENERAL STATEMENT.

In the early days of settlement the sole agricultural pursuit of eastern Washington was grazing on the open range. Owing, however, to natural laws of development, this industry has been displaced to a large extent by others which involve the tilling of the soil, and which, while yielding immensely greater returns, acre for acre, than grazing, require less capital than is required for the inception of a profitable stock-raising business. The directions of this later development have differed in Kittitas Valley and on the Columbia Plains. This fact, while due in part to differences in soil and climate, depends in a far higher degree on the conditions of water supply. Kittitas Valley is an irrigated region, while on by far the greater part of the Columbia Plains dry farming alone is practicable. While the discussion of open grazing, therefore, has been made general for the entire region, the other agricultural industries must be described separately for Kittitas Valley and the plains.

THE COLUMBIA PLAINS.

NATURAL CONDITIONS.

The cultivated portion of the Columbia Plains may be classified as plateau lands, meadow lands, and bench lands.

By far the most important in extent are the plateau lands, comprising the broad, level upland areas. The important natural conditions influencing agriculture upon the plateaus are (1) an arid climate, (2) absence of surface water for irrigation, and (3) a soil easily tilled, fertile, and peculiarly adapted to retaining and utilizing the scanty precipitation. The soil of the plateau lands is shown by chemical analysis to abound in the elements necessary to support plant life. Its peculiar virtues, however, are probably due less to its chemical than to its physical properties, its fine open texture rendering the plant food readily available and its friable character and freedom from stones making it very easy to till. Probably most important of all, however, is its behavior toward water. On the one hand, it is so porous that rain or melted snow is quickly absorbed by it, so that a smaller proportion is lost by run-off or by evaporation from puddles than would be lost if it were more clayey and impervious, and, on the other hand, it is not loose enough to allow the water to sink rapidly and become unavailable, as it does in a deep sandy soil. The spaces between the particles of the fine loam are so small that the water is held in them by adhesion or capillary attraction, and yields to the force of gravity only slowly and to a comparatively small extent. Therefore a large proportion of the slight precipitation is kept sufficiently near the surface to be used by the growing

wheat, and successful grain culture is possible with a rainfall that would be insufficient in a soil of less advantageous physical constitution. Dry farming of grain is the industry found most profitable under these conditions, and absorbs by far the greatest part of the energies of the farming population in this district, as well as in eastern Washington generally.

Far less in area than the grain lands are the meadows of Crab Creek, Grand Coulee, and Harrison Springs, characterized by heavy, moist, generally alkaline soils, and chiefly devoted to hay and pasture.

The bench lands comprise a comparatively small area on the terraces of Columbia River, where the sandy alluvial soil is irrigated with river water and produces a variety of crops.

DEVELOPMENT.

Grain culture.—The invasion of the land by the wheat industry has proceeded from the northeast. The settlement of the district about Ritzville, the thriving county seat of Adams County, dates back nearly a score of years, and the well-tilled farms, the numerous small but flourishing orchards, and the substantial farm buildings give this vicinity a gratifying aspect of prosperity. The villages on the Northern Pacific Railroad southwest of Ritzville and along the Great Northern are lively and growing, but glaringly new, and the hastily constructed, often unpainted frame house is the prevailing architectural type. The whole aspect of the country also speaks of its recent settlement. In the vicinity of Connell a large proportion of the wheat land has been broken in the past year, and many sections, protected from grazing by fences, still bear an abundant growth of bunch grass.

To the west also the frontier of the wheat belt is being pushed to the border of the desert. The land is dotted with the board shanties of homesteaders and with newly plowed squares that break the surface of the virgin ground. The clearing away of the strong and abundant sagebrush of this district preliminary to the first sowing is no small task, and many entire families are to be seen engaged in uprooting the shrubs, collecting them in wagons, and feeding them to blazing bonfires. The wholesale destruction of the brush is rather to be deplored, for the roots and lower stalks are used as fuel in many homes, and, while far from ideal for this purpose, must be of considerable value in a region where wood is so difficult to obtain.

The earlier settlement of the northeastern part of this region is not due to chance alone, but in part to better natural conditions, the greater rainfall giving this section a natural advantage over the country to the southwest. The appearance of the stubble after the fall harvest, as well as general report, indicates that it is superior in natural productiveness to the more arid districts. Part of the

apparent superiority is doubtless due to long cultivation of the land, for the best results are not obtained until about three years after the first breaking, when the roots of the sagebrush and bunch grass are quite decomposed. But after making all allowances it still seems unreasonable to expect as good returns in the recently settled districts to the south and west as from the older land, where crops may suffer heavily in years of especially light rainfall.

Exact data concerning the yield of wheat are difficult to obtain, but the general run of crops appears to be from 16 to 25 bushels per acre. Extremely large yields are not necessary for profitable culture, for the land is low in price and so easily worked that the cost of cultivation is much less than in heavier lands. It seems necessary, however, to work a considerable holding, and the ranches are probably in a majority of cases a section or more in area. The advantages of close settlement and small farms will perhaps never be attained.

Forage growing.—An important adjunct to the grazing industry is the culture of hay for winter feeding. There are numerous farms along upper and middle Crab Creek where hay is gathered from the meadows, the crop being stored in large stacks and the mown fields used as pastures for some time after harvest. The greater portion of this hay is fed on the ranches, for while a minor quantity is hauled to villages in the wheat lands it can hardly compete successfully with wheat hay and hay imported from the irrigated districts to the west. Unfortunately, the strongly alkaline character of the soil is fatal to the better forage plants, and the crop is of wild hay, very inferior in nutrient qualities to timothy, clover, or alfalfa. One hay ranch, perhaps the most important seen during this reconnaissance, is located on spring-watered land at the foot of Priest Rapids. At this locality the excessive moisture of the soil is prejudicial to domesticated grasses, though they have gradually been introduced to a slight extent, and the quality of the crop is thereby improved.

Horticulture.—Though horticulture in this portion of the State is not an important industry, orchards for supplying the needs of a household are very generally to be found on the older ranches, and larger ones are fairly numerous in the neighborhood of Ritzville. Two were seen on Columbia River, one irrigated by a water wheel and another by a small ditch from a neighboring canyon. So far as known, no shipments of fruit are made to distant parts of the State.

The natural conditions in the wheat country are unfavorable to fruit culture in many ways. The late frosts in spring, as experience has shown, are often fatal to the growth of peaches where they have been tried. The hardier apples often attain good size and quality, especially upon high ground, and prune trees are said to yield good

crops. Excellent pears are grown on the McMannamon ranch on middle Crab Creek, where the alkali of the soil is injurious to most other fruit trees. In the land bordering Columbia River there seems reason to hope that fruits may be grown with much success if extensive irrigation can be provided, for at Wenatchee, where temperature conditions are probably very similar, fruit culture is a flourishing industry.

Small fruits are said to thrive where their culture has been attempted, notably on the plateau west of Grand Coulee. Domestic vegetable gardens, with cabbage, corn, and other hardy plants, add to the comfort and convenience of many thrifty ranchers, but generally do not present a flourishing appearance.

Except at the two localities on Columbia River already mentioned, practically no fruits are irrigated in this region. Vegetables are sometimes watered by a small stream from the farm well, but no extensive, systematically irrigated gardens exist. If irrigation were possible there is no doubt that the quality and amount of fruit and vegetables raised in this region might be greatly increased. The extent to which irrigation may be practicable will be discussed later.

KITTITAS VALLEY.

NATURAL CONDITIONS.

The broad floor of Kittitas Valley presents a large area of alluvial soil of great natural fertility. The annual rainfall is too low to support agriculture in itself, but this deficiency is more than overcome by the conditions that have made it possible to irrigate a large portion of the land from mountain streams. The rather low mean temperature and the lateness of spring frosts is disadvantageous and makes horticulture less successful than in the Yakima region, where conditions are otherwise similar. The character of the agricultural industries of Kittitas Valley has been determined by the conditions thus briefly outlined. They may be classified as follows: (1) Growing of forage; (2) dairying; (3) grain culture, and (4) horticulture.

Forage growing.—In the winter feeding of sheep, cattle, and horses that range the neighboring hills and mountains a large amount of forage is consumed on the valley farms. But as the irrigated lands are eminently suited to the growing of hay and the warm dry months of summer enable the farmer to cure it thoroughly with small risk of injury by rain, a large surplus over that consumed locally is raised, the different varieties of hay, mainly timothy, clover, and alfalfa, constituting one of the most important crops of the region. It is baled and exported in large quantities and finds ready sale at

prices considerably higher than those obtained for the forage grown in the more humid region west of the Cascades.

Dairying.—The abundance of the best fodder and the excellent pasture afforded by hay fields in the intervals of cropping are conditions favorable for milch cattle, and dairying is an industry of considerable importance. While no large farms are entirely devoted to it, the great majority of ranchers produce small quantities of milk, which is collected daily by the several creamery companies and worked into excellent butter on a large scale. There are six creameries in the county, which is among the most important dairying counties of the State.

Grain culture.—Grain, including wheat, barley, and oats, in order of importance as named, is a crop of considerable magnitude, the greater part being grown on the marginal portions of the valley, where there is not sufficient water for the proper irrigation of hay.

Horticulture.—There are probably no ranches in Kittitas Valley with horticulture for their principal dependence, but nearly every thriving farm has its garden and orchard to supply domestic needs. Nearly all vegetables do well under irrigation, and considerable quantities of small fruits and vegetables are exported. The climate, as before noted, is unfavorable to most orchard fruits. Apples are the only ones grown in sufficient quantity for export; these are of excellent appearance and flavor, and generally freer from worms and other defects than the fruit of western Washington.

GEOLOGY.

GENERAL STATEMENT.

The area considered in this report lies wholly within the vast territory which, in Miocene time, was inundated by great floods of basaltic lava. Throughout the greater part of the region the basalt lies not far beneath the surface. Though for the most part covered with soil in the level upland stretches and gentle slopes, it is exposed in the walls of nearly every coulee or canyon. From this rock are carved the imposing but somber cliffs of the Grand Coulee, the gorge of the Columbia at the foot of Table Mountains, and the majestic Sentinel Bluffs. Its depth appears from the fact that nowhere within the limits of this reconnaissance has it been cut through by the streams that have so deeply trenched it.

Upon the basalt, in late Miocene time, there were laid down several hundred feet of sediments belonging to what is known as the Ellensburg formation. While these beds may have been deposited over the greater portion of the area considered, they have yielded with comparative readiness to erosion, and now occupy but a fraction of the land surface. In the White Bluffs of the Columbia this formation is splendidly exposed.

Since the deposition of the Ellensburg beds the layers of rock, originally horizontal, have been tilted and folded, and the land has been modeled to its present form by the work of water, ice, and wind.

STRATIGRAPHY.

YAKIMA BASALT.[a]

DISTRIBUTION AND VOLUME.

By reason of its vast extent and great volume the basalt of the Columbia basin is one of the most important volcanic formations in the world. Its greatest thickness is not less than 4,000 feet, and its area, including portions of Washington, Oregon, and Idaho, has been estimated at about 250,000 square miles. In Washington and Idaho the area underlain by it includes practically the entire Columbia Plains and that portion of south-central Washington designated the "foothill province," as well as a considerable strip along the southern border of the State, crossing the Cascade Range and extending west to the ocean.

East of the area immediately considered here the Yakima basalt, where its edge is exposed, is underlain by Tertiary sandstones. Just south of Wenatchee the northern face of Saddle Mountain is a lofty and precipitous cliff of basalt, at the foot of which lies a belt of low hills carved from the rather soft sandstones which occupy both sides of the river at Wenatchee, but soon thin out to the north. From a short distance above Wenatchee to the mouth of the Okanogan the boundary of the lava is marked by the Columbia, whose left bank is overlooked by a precipitous wall, with a top or "rim" of basalt, immediately underlain by old crystalline rocks, such as granite, gneiss, and schist; to the north these older rocks are not exposed, the basalt forming the entire wall of the canyon.

Near the Okanogan the boundary again crosses the Columbia, and is, in general, coincident with the southern border of the Okanogan highlands. On the northeast and the east the lava reaches up the lower slopes of the mountains in Idaho, remnants of it being found along the valley of Spokane River, about Cœur d'Alène Lake, and along the lower parts of the rivers flowing into it. Along the entire northern and eastern boundaries the surface upon which the basalt was poured out is supposed to have consisted of ancient, mostly crystalline, rocks. To the south, southeast, and southwest the basalt area extends for considerable distances into Idaho and Oregon, but its delimitation in these directions need not be dicussed here.

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[a] This name was first used by Mr. G. O. Smith in Water-Sup. and Irr. Paper No. 55, and is applied to the Miocene basaltic series of this region. The term "Columbia River lava," as used by Professor Russell, includes Eocene and Pleistocene lavas separated from the Yakima bacalt by important sedimentary formations.

ORIGIN.

The origin of a body of lava so vast and widespread is an interesting problem. It is a generally accepted view that the originally molten rock was forced up through great cracks or fissures in the crust of the earth; this theory is based on three kinds of evidence: (1) The volume and extent of the lava floods are so enormous that it is difficult to conceive of their eruption from ordinary craters; (2) the comparative rarity of the fragmental materials known as "tuffs," "breccias," etc., indicates a quiet welling up through fissures without the explosive action characteristic of crater eruptions; (3) the theory has received very positive confirmation of late years by actual observation of the fissures from which these floods came forth, filled with the cooled and hardened basalt and exposed by the erosion of the overlying flows. In the Cascade Mountains there is a great system of dikes in the sandstone beneath the basalt, which has been described by Professor Russell[a] and by Mr. George Otis Smith.[b]

The thousands of feet of basalt in the plains were not poured forth in one great outburst. The series is made up of a great number of layers or flows that can be distinguished in the field by means to be discussed in another section. It is estimated that about twenty such flows have been cut through by the river at Sentinel Bluffs. Each of these layers represents a distinct outpouring of basalt, the eruptions being separated by various intervals of time. In some cases these periods of rest must have endured for centuries, for at certain localities there are beds of soil between the layers on which trees have grown to considerable size, to be charred and buried by later flows. The basalt eruptions, especially in the later stages of their activity, were interrupted by periods in which there were accumulated other materials, consisting of volcanic ashes of a composition different from that of the basalt, and beds of sand, clay, or gravel, laid down in lakes or rivers.

The average thickness of the individual flows in this region is probably between 50 and 100 feet. Their extent, considered separately, must have been enormous, for it is rare to see the edge of a layer thinning out. This fact indicates that the molten rock was in a highly fluid condition and retained its fluidity long enough to spread out for great distances.

In addition to the massive flows that form the greater part of the series there are beds of fragmental volcanic material, such as bombs or smaller angular fragments of lava. Such materials either have been thrown up to great heights and spread out upon the surrounding

[a] Russell, I. C., Preliminary paper on the geology of the Cascade Mountains in northern Washington: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 1. 1899, pp. 121–122, pl. xii.

[b] Smith, G. O., Mount Stuart: Geologic Atlas U. S., folio 106, U. S. Geol. Survey, 1904.

country, or, mixed with hot volcanic water, have formed mud flows and run out on the surface in much the same way as true lava. Their formation was perhaps due to the partial choking of fissures by congealed material, and the building of craters where the pent-up subterranean forces found constricted vents. The fragmental materials are not so generally distributed nor so widespread as the massive flows; they are most numerous and thickest in the mountains, while in the Columbia Plains they form but an insignificant proportion of the basalt series.

LITHOLOGIC CHARACTER.

The textural and structural features of the basaltic rocks are of interest not only to the scientist, as throwing light upon the manner in which the lavas were erupted, but to the practical man also, for the deep water of this region is found chiefly in the basalt series. The lithologic characters will therefore be considered somewhat fully.

The texture of the basaltic rock, viewed in small specimens or fragments, shows a considerable range of variation expressive of the different rates at which the lavas cooled. The central portions of thick flows, where cooling has been slow, are often completely crystalline. In thin flows, or near the surfaces of thicker ones, the rock is of finer texture, is generally dull in luster, and does not show, to the unaided eye, the minerals of which it is composed. Where the basalt has been suddenly chilled, especially at the base of a flow, the lava may solidify as a black glass. From the practical standpoint, however, the most important fact in regard to texture is that the basalt is generally fine and compact, with no pores capable of allowing water to pass to any appreciable extent through the solid rock.

The structural characters of lava flows are dependent on conditions attending their eruption and cooling, and may best be described with reference to their origin.

SURFACE FEATURES OF LAVA FLOWS.

Molten lava, as it issues from the earth, is always charged with steam. While the lava remains underground the steam is intimately mixed with the molten rock and is prevented from expanding by the enormous pressure of the overlying crust. When the lava emerges on the surface, however, there is a sudden decrease in pressure, and the steam combined with the lava expands and collects in bubbles, which rise to the surface and burst, giving off the great clouds of vapor that always rise from a moving flow of lava. The solidification of the molten rock generally takes place, however, before the steam has entirely escaped, and the bubbles in the upper portion of the flow become, as it were, frozen, so that the upper surface of a lava flow has generally a vesicular or honeycombed character. It is

by this structure that the upper surface of a flow is best distinguished and the different flows distinguished from one another. The bottom of a sheet sometimes has this vesicularity in a minor degree, owing to the sudden chilling and solidification of that portion before it has freed itself from watery vapor.

Another common surface feature is that produced by the formation of a crust on the top of a flow and its subsequent disruption by the onward movement of the still liquid lava beneath. The rough scoriaceous layer, formed by the fragments of this crust cemented by other molten material, is called a flow breccia. Again, the crust formed upon the advancing front of a lava flow may often be broken and the fragments rolled under and incorporated in the bottom part of the moving sheet of molten material.

CONTRACTION PARTINGS.

After the lava has completely solidified it is still at a temperature enormously higher than that which it must ultimately attain, and a gradual cooling progresses for a considerable time. Cooling, in the case of basalt as of most other substances, brings contraction. This necessarily leads to the formation of joints and small fissures, dividing the rocks into blocks or plates of varying size and regularity, and such contraction partings are of universal occurrence in the basalts of the Columbia basin. The forms into which the lavas are thus divided are multitudinous, but are divisible into a number of classes, each of which will be briefly described.

Columnar jointing, generally perpendicular to the cooling surfaces and therefore most often nearly vertical, is the most universal and striking structural feature of the basalt flows (Pl. III, *B*). The columns vary greatly in size and regularity of form, their diameters ranging from a few inches to 6 feet. They are sometimes so straight, sharp cornered, and clean cut as to simulate the work of human hands. More frequently, however, they exhibit imperfections of form, the sides being warped and not parallel to one another. Cross sections of the most perfect prisms are oftenest pentagonal or hexagonal, but polygons of 4, 7, or 8 sides are also common.

The main vertical columns of the basalt flows are generally subdivided by secondary partings. Most universal is a transverse jointing, dividing each column into sections of varying lengths. An extreme development of such jointing is characteristic of certain flows, mainly in the upper portion of the series, which are primarily divided into vertical columns of large size and great regularity, these in turn being divided by slightly curved, nearly parallel, and very numerous horizontal partings into scaly fragments which overlap irregularly and do not extend entirely across the columns.

Another secondary parting, which has been described by Professor

Russell,[a] results in the formation of small columns perpendicular to the faces of the large vertical ones. This structure occurs where the vertical columns are irregular and especially large. In such cases the vertical cracks are comparatively wide, and probably allowed radiation and convection of heat from the sides of the columns. These were then cooling surfaces, and columns perpendicular to them were formed according to the usual law.

Lamellar parting parallel to the surface of flows is frequent near the upper and lower surfaces. This may extend for varying horizontal distances and is frequently combined with irregular vertical jointing.

FRAGMENTAL BEDS.

The beds of fragmental material thrown out from craters are made up of rough, angular, and generally scoriaceous fragments of glassy lava, imperfectly sorted, and not clearly stratified. The scarcity of such beds in the plains has been noted, and few localities can be cited where they are to be observed. In Dry Coulee, north of Adrian, a bed of red, slaggy, and porous fragments was seen, which carries water and supplies two or three springs. The north front of Yakima Ridge exhibits exposures which, by their erosion forms, appear to be coarse, fragmental basalts. To the west, as has been remarked, finer grained materials of similar nature are more plentiful, and considerable exposures are to be seen in Shushuskin Canyon and other ravines in the hills about Kittitas Valley. The fragmental materials are uncemented, very porous, and well fitted to absorb and store up large quantities of water.

MATERIALS INTERBEDDED WITH THE BASALT.

Materials other than basalt, interstratified with the lava, were observed only in the upper portion of the series. The most important of such beds is exposed in the escarpment of Saddle Mountain overlooking Crab Creek, and in the bluff opposite Craig's ferry. It is composed of fine grayish-white volcanic ash with very regular bedding, is about 100 feet thick, and is overlain by about an equal thickness of basalt. Similar ash beds in similar stratigraphic positions were observed on the sides of Kittitas, Squaw Creek, and middle Crab Creek valleys, but they do not seem to be continuous with the Saddle Mountain ash. The latter, indeed, is not observed on the west side of the river at Sentinel Bluffs, and seems to thin out or disappear to the east also.

About 500 feet below the top of the Sentinel Bluffs another light-colored bed about 40 feet in thickness is interstratified with the basalt and exposed at the same level in the cliffs on either side. This bed consists of what is known as an arkose sandstone, made up of grains

[a] Russell, I. C., Reconnaissance in southeastern Washington: Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, 1897, p. 45.

of quartz, feldspar, and mica. This rock, moderately coarse grained, friable, and of open texture, is well fitted to act as a water-bearing stratum.

ELLENSBURG FORMATION.

DISTRIBUTION.

Lying upon the surface of the basalt at numerous localities in east Washington is a series of supposed lake beds known as the Ellensburg formation,[a] from their having been first carefully studied near the town of that name.[b]

The distribution of similar beds in the same stratigraphic position is extensive, and they are found in great volume in various places in the western and the southern parts of the Columbia Plains. That these deposits are, or ever were, continuous over this broad area can not be asserted positively, but their general similarity at the various localities points to the existence of similar conditions of deposition over an extensive strip of territory east of the Cascade Mountains in the period following the close of the basaltic eruptions.

The present distribution of the Ellensburg beds in the area covered by this report is not so easy to determine as the barren aspect of the country leads one to expect. The formation is rarely exposed except where cliffs have been carved in it by ancient or modern streams, and its boundaries are mostly concealed by a thick covering of wind-blown soil. These conditions, combined with the hasty character of the work and the lack of a good topographic base, forbade anything like accurate determination of boundaries, and those represented on the map (Pl. I) are to be regarded as but roughly approximate.

LITHOLOGIC CHARACTER.

The character of the typical Ellensburg material of the Columbia Plains is shown by the following descriptive section of the exposure at the upper end of White Bluffs. The beds are described in ascending order.

Section of Ellensburg beds at White Bluffs, 1 mile below Koppen's ranch.

	Feet.
Sand, partly consolidated, and sandy clay, mostly red, weathering in part into small spheroids	25
Red tuffaceous sandstone, fine grained (ledge)	3
Soft, reddish, medium-grained sandstone	9½
Cross-bedded sand and fine gravel; fragrants mostly of scoriaceous basalt, somewhat rounded	5

[a] "John Day system" of Bull. No. 108 and Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, but so called erroneously, for the original John Day is of early Miocene age, and lies beneath the great basalt series. See Merriam, J. C., Bull. Dept. Geology, Univ. of Cal., vol. 2, No. 9, p. 276. The Ellensburg formation is probably equivalent to the Mascall formation of the John Day Valley.

[b] For detailed description of this formation in the type-region, see Smith, G. O., Ellensburg, Geologic Atlas, U. S., folio 84, U. S. Geol. Survey, 1903.

	Feet
Fine sand and silt, with small basalt pebbles	3½
Silt, not laminated, gray to terra cotta in color, nodular in upper part	24
Fine soft sandstone, gray green to terra cotta	20
Clay, gray green to pink	15
Greenish white clay, not laminated, checking into small fragments, with feldspar grains	70
Pale terra cotta silt, not laminated	7
Greenish clay	3
Pale terra cotta silt, obscurely laminated	5
Soft greenish clay	20
Above this, but probably not of the Ellensburg formation, are:	
Gravel, with pebbles of basalt 5 inches or less in diameter, incrusted with limy material; matrix light-colored silt and sand, partly cemented with limy matter	15
Sand, lower part with fine wavy lamination, upper part with a peculiar chambered structure, having thin, highly contorted partitions of cemented sand stained with iron oxide, with soft unconsolidated sand between	15
Total	225

The general character of this section offers some points of contrast with the typical section measured in the Ellensburg quadrangle.[a] The material in the White Bluffs is much finer, coarse sandstones being rare and coarse conglomerates entirely lacking. Cross-bedding, so common in the Naches Valley section, is not common in the White Bluffs. It is evident that the material has been carried far from its source and deposited under conditions of comparative quiet.

The Naches Valley section is characterized by a very large proportion of volcanic ash and tuff, mainly of andesitic composition. The extreme fineness of most of the White Bluffs rocks makes it difficult to prove their origin, but pumice grains and clear feldspar crystals are to be seen in some of the material, and dust scraped from a specimen of very fine grain is found, by the aid of the microscope, to consist of angular transparent fragments that seem to be volcanic glass. It is believed that ash erupted from volcanoes in the Cascade Range, carried a great distance by the upper air currents, and finally falling gently into the waters of a shallow lake, form the most important constituent of the White Bluffs beds. Certain of the sandy layers, however, were probably laid down by river currents.

The writer found no fossils of any kind in the Ellensburg formation in the region examined, though it is said that shells and bones have been found in the bluffs near Pasco.

In the Moxee artesian basin the most abundant supply of flowing water is obtained from the lower part of the Ellensburg formation. The White Bluffs section also shows an alternation of relatively per-

[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Washington: Water-Sup. and Irr. Paper No. 55, 1901, pp. 17–21; and Ellensburg quadrangle: Geologic Atlas U. S., folio 86, U. S. Geol. Survey, 1903.

meable and impermeable strata, which would seem favorable to the occurrence of artesian water, provided the requisite conditions of structure and supply are also present.

STRUCTURE.

GENERAL CHARACTER OF DEFORMATION.

At the close of the period during which the Ellensburg beds were deposited the rocks lay in a nearly horizontal position. Since that time they have been deformed in a manner that has a most important bearing on the artesian problems that will be discussed later on.

In his reconnaissance of a much larger area than the one here described, Professor Russell was led to the view that the characteristic orographic form of central Washington was the tilted fault block. The important economic bearing of this conclusion was recognized, as the presence of faults was held to be very discouraging to the hope of obtaining artesian water. The writer came to the field intending to investigate this point, and inclined to scepticism, for the examination of the Ellensburg quadrangle, also contained in Professor Russell's area, had shown that many of the supposed tilted blocks of the earth's crust were in reality unsymmetrical anticlines or folds in the strata.

The north face of Saddle Mountain, where it overlooks the lower stretch of Crab Creek, was cited by Russell as a very typical fault scarp. The topographic form here does indeed suggest faulting in a very striking way. South of Crab Creek a bold escarpment rises some 1,500 feet, exposing in section about 1,200 feet of basalt, overlain in order by a thick bed of white tuff, a flow of basalt, and a small thickness of Ellensburg formation proper. North of Crab Creek this lofty cliff is confronted by a low bluff of basalt, probably between 100 and 200 feet in height. A few miles to the northeast a gentle escarpment is seen, carved from the Ellensburg beds, here overlying the horizontally bedded basalt. It is obvious that we must have here either a normal fault with the downthrow to the north or a sharp flexure, the down-folded portion having been removed by erosion, leaving only the nearly horizontal strata on either side. Evidence bearing on the choice between these alternative views was gathered by examination of the Saddle Mountain front to the east and to the west of the great cliff.

On the west side of the Columbia, opposite the mouth of Crab Creek, the continuation of the mountain is bounded on the north not by a cliff, but by a steep slope, which passes continuously into the rolling surface at its base. The surface of this slope is nearly conformable to the structure of the basalt. The mountain shows no outcropping horizontal ledges, but rising through the mantle of soil,

sloping backward on the spurs and forward in the gulches, can be traced the outcrop of one or more especially resistant beds of black lava, having a dip a little steeper than the slope, but in the same direction. A little north of the base of this slope basalt can be seen with a very gentle dip to the south.

At another point, some 20 miles east of the mouth of Crab Creek, the north slope of the ridge was examined again, and a similar state of things observed. Crab Creek here flows in a canyon some hundreds of yards wide, bounded by precipitous walls about 100 feet high. Just to the south Saddle Mountain rises with a moderately steep terraced slope. For a few hundred yards back from the canyon's brink horizontal basalt, corresponding to that across the canyon, is exposed. On the lower slopes of the mountain the structure is concealed by terrace deposits and soil. Behind the uppermost terrace, however, the basalt is again exposed in a gully, where it shows a northerly dip of about 50°. The evidence indicates that there is here a sharp flexure and not a fault.

While the fact is not proved beyond doubt, the writer believes that this flexure, observed both east and west of the cliff, was once continuous along the entire front of Saddle Mountain; that the cliff along lower Crab Creek was produced by erosion, and that the flexure is here concealed below the sediments in Crab Creek bottom.

The existence of a fault along the Grand Coulee, which was asserted by Professor Russell, also appears open to doubt. In support of the fault hypothesis, Russell cites in the first place the existence of a down folding or monocline, exposed in section on the east wall of the coulee, apparently without any corresponding flexure in the opposite wall. This flexure, however, is not absent to the west, but is only obscured by the alluvial deposits laid on the terraces which have been cut in the down-folded part of the basalt. The monoclinal structure was observed in a gully northwest of Coulee City. The strike here, so far as could be observed, seemed more nearly north and south than on the east side, and the relations indicated that the monocline had been continuous across the canyon, but that the horizontal projection of its axis was probably somewhat curved. It seems unnecessary to suppose that there has been faulting. Further, the fact that the western wall of the coulee below the site of the cataract is much greater than that of the eastern wall is explained by Professor Russell as the result of faulting. To the writer it seems that this fact also could be accounted for by flexure. It is always to be borne in mind that the floor of a canyon half a mile wide and more or less covered by alluvial deposits may conceal important structures.

To sum up, it appears to the writer that the steep slopes supposed by Professor Russell to be fault scarps are, in the region considered

here, as in the Ellensburg area, the products of erosion and of sharp flexure in the basalt. It is necessary, however, in order to establish the view here advanced, to explain the remarkable fact that such important stream channels as the Grand Coulee, lower Crab Creek Coulee, and the canyon of the Columbia just below Priest Rapids have been intrenched along supposed lines of flexure. The most plausible explanation of this fact has been suggested by Professor Russell himself in one of his more recent publications,[a] in which he advances the theory that the location of the folds has been determined by the weakening of the crust through erosion along the stream courses. In other words, stream erosion, instead of deformation, has been the primary agent. This hypothesis appears to have much probability and to lend itself very aptly to the explanation of the course of lower Crab Creek and perhaps to the analogous position of the Columbia along the base of the ridge south of Saddle Mountain. In the case of the Saddle Mountain scarp, the surprise at its magnitude is diminished when we realize the fact, to be developed further on, that the Columbia, swollen beyond its present volume by water from a great glacier, once flowed in the channel now occupied by an insignificant and partly suballuvial stream.

CHARACTER OF FOLDS.

Folding is then considered by the writer as the prevalent type of deformation in the region here discussed, and he does not consider it probable that the injury of artesian basins by fissures is to be apprehended. In the western portion, lying in the foothill zone, the anticlines (structural arches) and synclines (structural troughs) are relatively pronounced, but they die out to the east, and in the wheat lands the basalt has suffered only gentle tilting, often imperceptible in amount.

With regard to direction, the folds fall into two systems. The sharper anticlines, and by far the greater number, trend nearly east and west. To this system belong the anticlines of Yakima Ridge and Saddle Mountain. Coexisting with the east-west system there are broad and gentle north-south folds, exemplified in the east slope of Table Mountain and the gentle westerly dip of the basalt underlying the wheat lands.

The form of the east-west folds is characterized by a lack of symmetry, the steeper side in the area dealt with in this paper being apparently always to the north. The contrast between the north and south faces of Saddle Mountain has been mentioned, and other more striking examples occur in the foothill region outside the area with which this report is concerned.

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[a] Russell, I. C., Geology and water resources of Nez Perces County, Idaho; Water-Sup. and Irr. Paper No. 53, U. S. Geol. Survey, 1901, p. 70.

The coexistence of two perpendicular systems of folds is perhaps favorable to the conservation of water under pressure, in so far as it tends to form basin-like structural depressions.

The specific structural features of the region whose general character has been discussed in the preceding paragraphs can be made plainer by the structure sections accompanying the geologic map than by lengthy verbal description.

PHYSIOGRAPHY.

Physiography treats of the development of the existing form of the land surface. In that development two classes of agencies have been concerned: (1) Forces, probably generated for the most part by the slow cooling and contraction of the earth, which deform the strata originally laid down in horizontal position and heave them up into the form of folds and tilted blocks; (2) the action of frost, water, ice, and wind, which modifies the masses raised up by these mountain-making forces. Agencies of the second class are mainly degrading in their effect—that is, they tend to tear down what the mountain-making forces have built up.

RELATION OF PHYSIOGRAPHY TO STRUCTURE.

The manner in which the Miocene rocks have been deformed has been discussed under the heading "Structure." The relation between this and the form of the land surface in the region considered is unusually close. There is over the greater part of the earth's surface a lack of concordance between the topography and the dip of the underlying rocks, because erosion has so deeply modified the original form of the uplifts as to make their character unrecognizable without careful study. Here, however, the principal uplifts and the basins or troughs between them have retained, in a general way, their original form. For instance, Kittitas Valley is a striking example of a structural basin in which the rock layers on all sides dip toward the center, while the portion of Table Mountain that lies within the area considered here is a structural elevation, its east face being a clear example of a "dip slope." The profile of the south face of Saddle Ridge also is in harmony with the arching structure of the underlying basalt so clearly exposed in Sentinel Bluffs. It may be said, in general, that the extensive gentle slopes in this region, unbroken by outcrops of rock ledges, are more or less nearly parallel to the underlying strata and are expressive of the structure of the rocks. In contrast to these comparatively gentle structural slopes are the bold cliffs exposing the rocks in section. These features are mainly the work of rivers, whose effect on the topography may now be considered.

WORK OF STREAMS.

The conspicuous features formed by stream erosion are the canyons of the Columbia and the Yakima with their tributary streams, and the dry coulees of the wheat lands. Less prominent are the features that represent the depositing rather than the cutting activity of the streams, namely, the gravelly flood plains and terraces. A study of the topographic forms that have resulted from the work of streams throws much light on certain of the later episodes in the history of this region.

RELATION OF STREAM COURSES TO STRUCTURE.

When we consider the relation of watercourses to the structure of the rocks, the streams of the region are divisible into two classes—those whose courses seem to have been determined by the structure of the underlying rocks, and those whose courses are independent of rock structure.

Consequent streams.—To the first class, which are technically designated consequent streams, belong the majority of the smaller streams of the region. The creek draining Willow Springs, for example, and that flowing from the Clerf Spring, flow down pitching structural troughs or synclines. Another large class of small streams or channels seem to have been located by water flowing down a structural slope. Examples of canyons originating in such a manner are afforded by the gulches draining Table Mountain and Saddle Ridge.

Antecedent streams.—The most striking examples of the second class of streams are Columbia and Yakima rivers, which in several instances cut squarely across great structural arches in the basalt. The Yakima leaves Kittitas Valley not by the lowest portion of its rim, but by a deep gorge cut across Manastash and Umptanum ridges. Lower in its course it cuts other anticlinal ridges lying outside the area of this survey. Columbia River in like manner cuts across Saddle Ridge in a direction at right angles to its crest line. Another instance is furnished by Moses Coulee, which has cut its way through the Badger Mountain uplift without regard to structure, forming a canyon whose size is especially remarkable when we consider that for ages it has not contained a perennial stream.

The formation of the gorges thus briefly described can be explained only on the supposition that the streams which formed them are antecedent to the structure, or, in other words, that their courses were established before the upfolding of the basalt and Ellensburg beds began and were maintained throughout its progress. The arches were raised up against the down-cutting rivers as a log is pushed against a whirling saw. The uplift must have been in general an extremely slow process, since in most cases there is no evidence to

indicate that the rivers were ponded, as they would have been if the rise had been so rapid that they failed to maintain their courses. The sudden uplift of Saddle Mountain would have deflected the Columbia and caused it to find an outlet over the lowest point in the dam, far to the east of the gate it actually made for itself. There is some reason to suspect, however, that the river was deflected by the next uplift athwart its course, and the eastward bend at the foot of Priest Rapids may have been due to the inability of the river to cut down against the rising ridge along whose face it flows for many miles below, to clear its lower end in the great sweep to the east inclosed on the left by the White Bluffs.

The three examples cited are not the only antecedent streams in the region. Crab Creek crosses an anticlinal arch of slight elevation below Moses Lake, while its course along the western portion of Saddle Ridge was not determined by structure. If the writer is correct in discrediting the hypothesis that the cliff in that locality is a fault scarp, the antecedent character of Crab Creek may be taken as explaining its origin, according to Professor Russell's hypothesis cited on page 39.

ORIGIN OF COULEES.

The topographic character of the coulees in the wheat lands proves that they have been produced by stream erosion It is, however, perfectly obvious that they could not have been eroded, no matter how much time were allowed for the process, during the existence of the present arid climate. A few of the coulees have streams, perennial though insignificant in comparison with the canyons they occupy, but the majority never contain continuous surface streams, even in the rainy season. It is necessary to suppose that the coulees were eroded in a time long past, when the region had a fairly abundant rainfall. The causes which determined the formation of the Grand Coulee were, however, exceptional, and will be discussed later.

TERRACES AND GRAVEL DEPOSITS.

In the formation of their canyons the streams did not cut down steadily and without stopping. The task was accomplished in a somewhat spasmodic fashion, with alternating periods, during some of which the streams were occupied in sinking channels into bed rock, while in others they were occupied in filling with gravel those already cut. These episodes in the history of the streams are recorded in the terraces and gravel deposits of the stream canyons.

Terraces of well-rounded basalt gravel are found along all the coulees of the wheat lands, such material being especially well exposed near Connell. Similar deposits are extensively developed near Coulee City and east of middle Crab Creek and of the foot of Moses Lake. Gravel terraces are found at high levels along Columbia River, the

best examples occurring below Priest Rapids and in the gorge along the foot of Saddle Mountain. Great volumes of gravel underlie the central portion of Kittitas Valley and are well exposed in section on the banks of Yakima River.

Ancient gravels are found not only in the terraces above the present stream levels, but underlie the existing stream beds in many cases to considerable depths. At Connell records of well borings have shown that the bed of the coulee is filled with gravel to the depth of at least 180 feet. Great depths of gravel are also found in borings along other coulees. The Columbia flows on gravel through the greater portion of its channel, but has reached bed rock at Priest Rapids and perhaps also at Coyote Rapids.

The history to be read from these gravel deposits is briefly as follows: (1) There was a period during which the streams, actively cutting downward, carved a system of canyons in bed rock deeper than those which exist at present; (2) a period succeeded during which the streams were overloaded with gravel and filled up their bed-rock channels to depths attaining, in the case of the Columbia, at least 300 feet; (3) there was a second period of down cutting, in which the streams cleared out the gravel from their bed-rock channels to a greater or less extent; temporary halts in the process of down cutting are marked by the lower terraces; (4) the large and numerous streams that carved the canyons dwindled because of the arrival of the present arid climate, and the down cutting into the gravel deposits practically ceased except in the cases of Columbia and Yakima rivers.

The gravel deposits of the region are not only of scientific but also of economic interest, as the surface wells of the region are mainly located in the gravels on the valley and coulee bottoms.

GLACIAL HISTORY.

There was a period, recent as time is measured by the geologist, but long before the beginning of human history, when the valleys of the northern Cascades and of the Okanogan highlands were filled with immense glaciers, the largest of which reached the plains before they were melted in the warmer air of the lower country.

The greatest ice river of eastern Washington flowed down the Okanogan Valley, which it filled to a depth of several hundred feet. Upon reaching Columbia River Valley this glacier expanded. It seems not only to have dammed the Columbia, but to have filled its profound canyon down to the outlet of Lake Chelan, and to have spread out over the plateau embraced by the Big Bend for about 35 miles to the east of this point. The southern limit of the Okanogan glacier is marked, according to Salisbury,[a] by a terminal moraine

[a] Salisbury, R. D., Jour. Geol., vol. 9, 1901, p. 721.

extending from Chelan Falls to a point about 5 miles north of Coulee City, in a great curve convex to the south.

The eastern end of this moraine was seen in the course of this investigation. It is a low ridge or, more exactly, a slightly elevated hummocky zone formed of material pushed up in front of the advancing glacier or carried on its surface and stranded where the ice melted. Borne thus upon the southward-moving ice were many huge blocks of basalt and fewer of granite. Some of these were stranded upon the moraine, and many are to be seen on the plateau in the vicinity of St. Andrew. One of them, an enormous block of basalt, stands near the brink of the Grand Coulee and is a striking landmark visible for many miles. In early days it served to guide travelers from the east, and was generally known as Pilot Rock. Other large bowlders are strewn upon the terraces at Coulee City and Ephrata, and seem to have been dropped from icebergs that broke from the glacier front and floated for some distance southward on the stream which then filled the Grand Coulee.

While the Columbia was dammed by the Okanogan glacier it flowed along its western side southward into Crab Creek Valley, which was probably eroded to a considerable depth before this time. During the existence of the ice dam the Grand Coulee was carved, lower and middle Crab Creek Valley was much enlarged, and extensive deposits of gravel were laid down about Ephrata and Moses Lake. When the glacier retreated up Okanogan Valley the Columbia resumed its former channel.

WIND WORK.

Under the arid conditions that have prevailed in historic time water erosion has had comparatively little effect in modifying the general surface of the land. Various conditions, however, have enabled the wind to do considerable transportation; the air currents, which have a prevailing southerly direction, are strong and frequent, while the soil is dry and loose textured, and is but slightly protected by the meager growth of grass and shrubbery.

SAND DUNES.

The most striking evidences of wind work occur in the sandy region that borders the Columbia, where groups of sand dunes of very perfect form are to be seen. They exhibit the characteristic wave-like profile, their steep sides constantly facing in the north or leeward direction, and the process of their growth and shifting is to be seen on any windy day. Other sand dunes of remarkable size and extent are to be seen below Moses Lake, which, as before remarked, owes its existence to them. Low hillocks, built up mainly by wind action, are also to be seen on the plain south of Saddle Mountain, but the dune form in these is not so pronounced as in the

A. GRAND COULEE.

B. RECLAIMED MARSH LAND NEAR WILSON CREEK.

ones previously mentioned, probably because of the vegetation that has found a foothold upon them and allows the sand to move less freely.

SOILS OF THE WHEAT LANDS.

In the wheat lands also the wind has given the final touches in the molding of the surface. The minor branches of the dry coulees, carved originally from basalt, have had their once rugged sides mantled with fine wind-blown soil, which conceals the bed rock except in widely separated exposures. That the soil mantling the slopes of the coulees has been laid down by wind seems obvious. The present writer further believes that the thick soil of the wheat lands also is mainly wind deposited, or eolian. It has been assumed by most writers who have touched upon the subject that the typical wheat soil of the Columbia Plains is residuary, derived from the decomposition of the underlying basalt. Professor Russell, however, is the only geologist who has supported the residuary hypothesis by extended argument. In his report on southeastern Washington he advocates the view that the wheat soils are essentially residual, but superficially modified by wind action.[a] In his later description of the Nez Perces region in Idaho he reaffirms the views expressed in the earlier paper, and applies the theory of residuary origin to the wheat soils of Idaho.[b] The writer's observations in east-central Washington have led him to believe that the wheat soils are not residuary, but wind deposits. This belief is based primarily on the following facts observed in the field:

(1) The thickness of the wheat soils, as shown by well records, varies according to location from 50 feet to a minimum probably averaging something like 25 feet. They mantle completely most of the broad plateau surface and the gentle slopes, often concealing the bed rock in the smaller gullies for many miles. The greatest thicknesses, however, seem generally to be on the brows of slopes, where there are the most favorable opportunities for accumulation of wind-blown material.

(2) The physical properties of the wheat soils are highly characteristic and remarkably uniform. In texture they are fine loams, very light, open, and friable.

(3) Their prevailing color is a light tawny brown, varying according to the amount of organic matter present, but conspicuously in contrast to the deep red tints which one would expect in a soil derived from the decomposition of a rock so rich in iron oxides as basalt.

(4) When exposed in vertical sections the wheat soil is seen to preserve its surface characters with remarkable constancy down to the

[a] Russell, I. C., Reconnaissance in southeastern Washington: Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, 1897, pp. 60-64.

[b] Russell, I. C., Geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Paper No. 53, U. S. Geol. Survey, 1901, pp. 44-48.

solid basalt beneath. There is rarely any lamination perceptible, such as would suggest deposition by water.

(5) In all sections observed by the writer, moreover, the division between the basalt and the tawny loam is sharp, without any transition from fresh rock, through decomposed rock and soil with rock particles, such as would be expected were the soil residuary.

The sharp definition between soil and basalt seems absolutely to forbid the belief that the soil is residuary in the strict sense—that is, resting in the place of its formation. It must, therefore, be a transported soil. The absence of lamination in the soil, the fineness of its texture, and the absence of any particles so large as to be incapable of wind transportation seem almost to demonstrate that the agency concerned in its deposition was wind. Granting this much, however, it might still be argued that the material was derived from the decomposition of basalt and only slightly removed from its source. But the wheat soil's evident poverty in iron oxide, and its freedom from any recognizable particles of basalt, are facts which strike the observer in the field as discordant with such a supposition, and the results of detailed chemical analyses give additional evidence in the same direction.

Comparative analyses.—There are on record many analyses of the wheat soils of the Columbia Plains, made in the agricultural experiment stations of Washington and Idaho. It appears, however, that they are generally analyses merely of the portion soluble in hydrochloric acid, and while they may serve the purpose for which they were made they do not give the true chemical composition of the samples and throw but little light on the question of their origin. Partial analyses of basalt and of the overlying soil from Dayton, Wash., have been made by Dr. G. P. Merrill and are published by Professor Russell,[a] but the soil analysis differs so markedly from all those emanating from the experiment stations as to throw increased doubt upon their availability.

In view of these facts analyses were made in the chemical laboratory of the Geological Survey of a typical wheat soil and of an undoubtedly residuary soil. The following tables are designed to facilitate the consideration of the available chemical evidence bearing on the origin of the wheat soils. In Table A the results of the last-mentioned analyses are exhibited side by side with an analysis of basalt similar to that underlying the wheat lands from the Mount Stuart, Washington, quadrangle. In Table B the analyses given in the first table are presented in a condensed form for more ready comparison with the analyses given by Professor Russell.

[a] Russell, I. C., Reconnaissance in southeastern Washington: Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, 1897, p. 61; and Geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Paper No. 53, U. S. Geol. Survey, 1901, p. 44.

TABLE A.—*Analyses of basalt, residuary soil, and wheat soil made in Geological Survey laboratory.*

	I.	II.	III.
SiO_2	54.50	52.95	65.43
Al_2O_3	14.43	15.69	13.96
Fe_2O_3	2.17	[a]11.85	[a]5.35
FeO	8.80		
MgO	4.24	2.05	1.54
CaO	8.01	4.40	2.90
Na_2O	3.05	2.09	2.42
K_2O	1.29	1.11	2.08
H_2O at 105	.29	2.19	2.32
H_2O above 105	1.09	4.01	2.42
TiO_2	1.69	2.57	.87
P_2O_5	.21	.19	.20
C	.....	.63	.49
Total	99.77	99.72	99.98

[a] Comprises all iron oxide reckoned as Fe_2O_3.

I. Basalt, Mount Stuart quadrangle; Hillebrand, analyst; contains also small quantities of SO_3, MnO, BaO, and SrO, aggregating 0.36 per cent.

II. Residuary soil, Hanson Creek; Steiger, analyst.

III. Virgin soil (surface), south of Krupp, Wash.; Steiger, analyst.

TABLE B.—*Analyses of Table A (condensed) compared with analysis given by Professor Russell.*

	I.	II.	III.	IV.	V.
SiO_2	47.35	54.40	52.95	65.43	63.58
Al_2O_3, Fe_2O_3, etc	[a]34.38	[a]28.28	[a]30.30	[a]20.38	[a]22.36
MgO	4.43	4.24	2.04	1.54	1.82
CaO	8.27	8.01	4.40	2.90	2.76
Na_2O	2.55	3.05	2.09	2.42	2.02
K_2O	1.33	1.29	1.11	2.08	2.27
Ignition	.95	1.38	6.83	5.23	4.37
Total	99.26	100.75	99.72	99.98	99.33

[a] Comprises all iron oxide reckoned as Fe_2O_3, plus the P_2O_5 and TiO_2.

I. Basalt; Merrill, analyst; given by Russell.

II. Basalt, Mount Stuart quadrangle; Hillebrand, analyst.

III. Residuary soil, Hanson Creek; Steiger, analyst.

IV. Virgin soil (surface), south of Krupp; Steiger, analyst.

V. Surface soil, wheat field near Dayton, Wash.; Merrill, analyst; given by Russell.

Upon comparison of the analyses in Table B it is evident that I and II are very similar, and in view of the fact that the basalts of the Yakima series do not vary widely in petrographic character, analysis I in Table A may be taken as sufficiently representative of the basalt series for the present purpose. The similarity also of the soil analyses IV and V is astonishingly close and strongly suggests that the two soils are of the same nature. Comparison of the analyses in Table A should therefore give some valid evidence in regard to the general question of the origin of the wheat soils.

A mere glance at the table shows a general similarity between I and II and a general dissimilarity of III from either of the others. When we proceed to more detailed comparison of the proportions of the various oxides, the most significant facts brought out seem to be the following:

(1) The alumina in III is slightly less than in I and II.

(2) The iron oxides are about equal in I and II, but are much less abundant in III.

(3) The alkalies in II show, as compared with I, a notable decrease, relatively greater in the case of potash; III contains little less soda than I and more than II, while the potash is 60 per cent more abundant than in I.

Residuary soils generally show, as compared with the parent rocks from the decomposition of which they are derived:

(1) Increase in the proportion of alumina. In calculating the percentage of each constituent lost in the process of decomposition the alumina is generally assumed to remain constant.

(2) Equally or more abundant iron oxide, except where organic matter is present and reduces the iron to the soluble protoxide. There is no evidence, however, that the conditions in this region ever favored the removal of iron oxides by leaching.

(3) Greatly decreased percentage of alkalies, which are the most soluble constituents of the rock.

It is sufficiently obvious that the differences between the wheat soil and the underlying basalt are not only considerable, but, what is much more significant, are not of the character naturally to be expected if the wheat soil were derived from the basalt. The discrepancies between the facts of the case in point, on the one hand, and the usual results of weathering, on the other, if they do not quite invalidate the residuary theory, at least require explanation. In the writer's opinion, the chemical data available appear to agree with the field observations in supporting the theory that the soils in question were not derived from the decomposition of the basalt.

Transporting power of the wind.—The competency of the wind as a transporting agent must be considered, however, in judging of the validity of the theory here advanced. That wind is, in the Columbia

Plains, a transporting agent of importance is a fact which must impress anyone who travels through the region. Winds of prevailing southerly direction blow with strength and frequency, while the soil is but very imperfectly protected from them by vegetation. Blinding dust storms are by no means rare, and clouds of fine dust envelop every traveler who drives along the roads. On the whole, there appears no reason to doubt that the wind is capable of doing the work assigned to it under the hypothesis here advanced.

Source of the soil.—The argument, however, would not be complete without suggesting a source for the material if we reject the supposition that it was mostly derived from basalt. The writer believes that the principal source lies in the desert southwestern quarter of the Columbia Plains, where the basalt is overlain by the soft sedimentary beds of the Ellensburg formation. This material is thought to have been washed down and loosened by the agency of water, and thus put in such form that it might readily be transported by wind.

HYDROLOGY.

INTRODUCTORY STATEMENT.

The remainder of this paper is devoted to the consideration of water supply proper. The various kinds of water resources will be described and their availability considered, and the attempt will be made to show how the water supply of the region may be increased. The sources of supply available in the region are streams, springs, and wells, which will be considered in the order named. The first two classes of water resources will be treated rather briefly, but the wells, being more important, will be discussed more fully.

The wells may be divided into two classes—first, surface wells, generally dug by hand in loose materials like soil, sand, and gravel, lying on the surface of the bed rock; second, deep wells, including those in which the underlying older rocks are penetrated, generally by means of a dril, to a considerable depth. Surface wells derive their supplies from rain or snow that falls in their immediate vicinity and percolates downward until some impervious material is reached, while deep wells generally tap beds of porous rock saturated with water that has been absorbed at some distant outcrop and has traveled underground often for great distances.

The most important question dealt with in this paper is that of the capabilities of deep wells, one of the principal objects of the investigation having been to determine whether in any part of the region examined deep wells could be made to yield artesian flows. In discussing this problem a number of districts may be marked out, in each of which the conditions affecting the deep underground waters are similar. For each of these districts the artesian conditions will

first be discussed from the theoretical standpoint; the evidence afforded by the wells actually sunk will then be presented, and conclusions will be drawn in regard to the probability of obtaining surface flows. Suggestions will next be presented with a view to directing intelligent tests for artesian water and to economically using all the water obtainable. The paper will end with a brief recapitulation of the important conclusions and suggestions in regard to deep wells.

The preceding portions of this paper have been designed mainly to serve as an introduction to the portion on hydrology proper, as the discussion of the artesian problems will involve frequent reference to the facts regarding the character and structure of the rocks underlying the region.

STREAMS.

COLUMBIA PLAINS.

CRAB CREEK.

From the fact that the valley of Crab Creek was eroded by a much larger stream than occupies it at present it has resulted that the existing stream has been unable to maintain a graded channel. Certain irregularities in the ancient channel and modifications produced by the drifting in of sand and silt have been sufficient to cause ponding in certain localities, with the consequent formation of marshes, and in some cases the water of the creek vanishes during at least a part of the dry season beneath porous surface deposits, to reappear in full force at a lower point.

The meadows used for the growing of hay and as pasture are generally sufficiently watered by the underflow of Crab Creek, but in certain localities ditches have been constructed to water portions of the bottom too high to utilize the underflowage.

On the other hand, some considerable areas of marshy land have been or are being reclaimed by drainage, a notable instance being afforded by the marshy tract extending from Krupp to Wilson Creek. This is being gradually drained, and a large amount of certain localities ditches have been constructed to water portions of the bottom too high to utilize the underflowage.

COLUMBIA RIVER.

The use now made of Columbia River water, in its course through this region, is comparatively insignificant. A small amount of water is raised by water wheels, three or four of which are situated on the right bank of the Columbia below Priest Rapids. The availability of this method is limited by the comparatively small amount of land low enough to be watered by such means. In only one

instance is any other means of irrigation used. This is in the case of the Babcock ranch, near Trinidad, where one of the lower terraces has become the site of a hay ranch, which is irrigated successfully by means of a gasoline pump and a number of windmills.

It is natural for the traveler in this region to be disappointed at the slight utilization of Columbia River water and to inquire into the possibility of bringing more of it upon the bordering arid lands, especially the extensive tract between the Saddle Mountains and the easterly stretch of the Columbia, the general elevation of this tract being about 300 to 400 feet above the Columbia at Sentinel Bluffs.

Two possible methods of accomplishing this suggest themselves. The first involves the construction of a ditch from some point on the upper Columbia or on some tributary of the Columbia. This idea, when scrutinized, offers great engineering and financial difficulties. To reach a point on the Columbia of sufficient elevation would necessitate the construction of many miles of flume along precipitous portions of the river gorge. To bring water from one of the tributaries flowing into the Columbia from the Cascade Mountains on the west would involve obstacles which, if less serious than those presented by the first-mentioned plan, would still be extremely formidable.

The second apparently possible method is to raise the water from the Columbia by pumping, obtaining the power by utilizing the considerable fall of the river through Priest Rapids. The practicability of such a scheme must be determined by experienced engineers after examination of the ground, and the suggestion is made here only tentatively.

It is said that surveys were once made for a ditch to head at Sentinel Bluffs, with the hope of irrigating a large part of the sandy land below the great bench, but it was found that the ditch level abutted against the escarpment of a terrace about 150 feet above the river and fairly close to its shore at a point a few miles east of the Harrison ranch. The project was therefore abandoned, as it was considered that the small area of land irrigable by such a ditch would not justify its construction, while to secure an increase of elevation sufficient to overcome the obstacle mentioned would require that the ditch be begun above the Sentinel Bluffs and far up the rocky gorge north of Crab Creek.

KITTITAS VALLEY.

YAKIMA RIVER AND TRIBUTARIES.

The greater part of the arable land in Kittitas Valley is more or less efficiently irrigated. The ditches may be divided, according to the source from which they derive their supply, into two classes: (1) those leading from Yakima River, and (2) those obtaining water from the tributary streams that head in the mountains to the west,

north, and east. The ditches of the first class are nearly all controlled by corporations, and data concerning them are comparatively accessible. Those of the second class include only two incorporated ditches and a large number of private ditches, concerning which it is difficult to obtain accurate information.

Canals from the Yakima.—The oldest large canal on Yakima River is that known as the Ellensburg ditch, controlled by the Ellensburg Water Company. The construction of this ditch was begun in 1885, and the greater portion of it was completed in 1887. It was enlarged and extended 3 miles in 1892. The cooperative plan upon which the controlling corporation was organized is typical for the Ellensburg region.

The ditch was built by the farmers in the irrigation district covered by the ditch, stock in the corporation being given in payment for the labor performed. The original value of the stock was placed at $5 per share, of which 8,000 were issued. The ownership of each share entitles the holder to one-half a miner's inch of water. The price of water is fixed each year and the money received applied to the payment of current expenses, which are low, and to the liquidation of indebtedness incurred in the construction of flumes. The present price of water is about $1 per inch, or 50 cents per acre, but it is expected, after the indebtedness is cleared off, to reduce this to about 50 to 70 cents per inch.

The intake of the canal is at a point on Yakima River about 7 miles above Ellensburg. It sweeps about the eastern side of the valley, doing duty for most of its entire length of about 20 miles, and terminates at a point about 5 miles southeast of Ellensburg. Its fall is 22 inches to the mile. The total area irrigated by this canal is about 8,000 acres.

The Bull canal is named for Walter A. Bull, by whom it was first constructed in 1885 for the irrigation of his own farm. It was afterwards enlarged and used by a score of farmers, who organized a corporation, to which the water rights of the ditch were transferred in 1898. The plan of organization was cooperative, and similar to that of the Ellensburg Water Company. There are 50 shares of capital stock, each valued at $75 and entitling the holder to 20 inches of water. The capacity of the canal is thus about 1,000 inches, or sufficient for the irrigation of some 2,000 acres. The charges for water are extremely low. They average about 20 cents per inch per annum, and attained in 1898 the merely nominal figure of 5 cents per inch.

The water is taken from Yakima River, and first does duty in supplying power for the flour mill at Ellensburg. From the tailrace of the mill the water is led into the lower part of Wilson Creek channel, and this natural trench is made to serve the purposes of a ditch.

The only other large ditch from Yakima River is that of the West

Side Irrigation Company, which begins about 2 miles above Thorp and irrigates about 7,000 acres on the west side of the river. It has a capital stock of $30,000, divided into 600 shares of $50 each. A share entitles its holder to 6 inches of water. The cost of maintenance is about $1,000 a year, or about 35 cents per inch of water delivered.

The Cascade Canal Company has just completed a canal higher than any previously constructed. It has been financed locally and is to be operated on cooperative principles. The intake of the canal is at Dudley, about 4 miles above Thorp, and its total length is about 42 miles. The company has built a dam across the outlet of Lake Kaches that will raise the water about 15 feet above low-water mark. The cost of the canal is about $125,000, and it will irrigate about 16,000 acres of land. The same company expects to construct a higher canal in the near future.

Canals from tributaries of the Yakima.—Of the canals that take water from the mountain streams, only two are incorporated. These are the Taneum and the Manastash ditches, named from the streams from which they derive their respective supply. They are among the oldest ditches in central Washington, both having been constructed about 1875.

The larger of these is the Taneum ditch. It was constructed on a cooperative plan. The cost of construction was a little more than $1,000, and the corporation was capitalized at $2,000, divided into 40 shares. The value of water is so great, however, that $500, or twenty times the par value, is now paid for a single share. The capacity of this ditch at high water is about 5,000 inches, but the supply often becomes deficient in late summer.

The Manastash ditch irrigates a smaller area than the Taneum. Its maximum capacity is 1,200 inches; after July 1 the supply is cut down to half this amount. The capital is about $1,500, but the actual value of the ditch is now estimated at about $25,000.

In addition to the canals above described, there are a great number of private ditches taking water from the small streams. It is supposed that the total acreage irrigated from these ditches is larger than that supplied by the larger incorporated ditches. However, those who are dependent on the supply of the mountain streams often suffer from an insufficiency of supply in the latter part of the summer, there being generally no more than enough to mature grain or a single crop of alfalfa.

CONSERVATION OF THE SUPPLY.

For the amelioration of this condition it is to be hoped that storage reservoirs in the mountain canyons may be constructed at some future time, so that the abundant run-off of the rainy months can

be stored and allowed to come down to the thirsty valley lands in the dry season, when it is needed. The writer is unable to suggest any sites where reservoirs can be constructed economically, but believes that future necessity may stimulate the discovery and survey of suitable reservoir sites.

It is also a matter of the highest importance to make certain that the means supplied by nature for the equalization of the run-off by the storage of water in snow banks and in the sponge-like mantle of humous soil and rootlets that is spread over the shaded forest areas shall be preserved to the fullest possible extent. It is probable that the regulations in regard to the pasturing of sheep in the forest reserves might advantageously be made more stringent. Greater pains should also be taken to prevent the spread of forest fires and to secure the punishment of those who start them. There can be no doubt that the origin of a great number of forest fires is traceable to criminal neglect, if not to the deliberate intention of those whose interest is furthered by the clearing of the land. There is much testimony to the usefulness of the foresters in checking forest fires, but it is also certain that the present force is inadequate to prevent immense annual destruction under existing conditions.

SPRINGS.

In the early days of the settlement of the arid Columbia Plains water for the use of man and beast was almost entirely derived from springs. Even up to the present time many families are entirely dependent upon springs for their supply, which they not infrequently haul for many miles either in barrels or in specially constructed tank wagons. The more provident farmers have cisterns sufficiently capacious to contain several tank loads, and are thus enabled to hold a supply in reserve to tide over periods when time can not be spared for hauling.

The springs of this region may be classified as surface, canyon, and fissure springs. The great majority belong to the first two classes.

SURFACE SPRINGS.

The term surface springs is applied here to springs in surface deposits overlying the basalt, supplying water that has not sunk to any considerable depth. These in many cases appear to be formed by the gathering of surface water that has percolated down through the soil mantle and, flowing slowly over the underlying surface of comparatively impermeable rock, has become concentrated in the stream channels that furrow its surface. The water, small in amount, is for the most part concealed in the alluvium and the wind-blown silt with which these channels are filled, and emerges only in excep-

tionally favorable localities. Springs of this character are observed on the line of the Northern Pacific at Paha, and are of especial importance on the slope leading from Coulee City to the plateau northwest. It is probable that at this locality they are largely in the material of the great moraine that terminates in this neighborhood. In the sloping gullies these springs are numerous enough to furnish the domestic supply for the ranches there situated.

CANYON SPRINGS.

What are designated canyon springs are generally situated in the walls of coulees. In genetic character they do not differ widely from springs of the first class. The water supplying them has come from no great distance. In some cases they are supplied by rain water that is absorbed by the soil and finds its way slowly through crevices in the columnar basalt to a porous layer of scoria underlain by relatively impervious rock; favored by a slight slope, the water then flows to some outlet in a canyon wall. In other cases it is probable that much of the supply is absorbed at another edge of the water-bearing stratum exposed on the slope of a not far-distant canyon from which there is a decided dip toward the spring. Black Rock Spring, in the first coulee south of upper Crab Creek, appears to be a case in point. The water there rises, apparently under slight pressure, through the alluvium at the base of the northern wall of the coulee. At Wilson Creek, on Crab Creek just north of this spring, the basalt has a dip of 5° to the south, and it is possible that some water falling on the side of Crab Creek Canyon finds its way to Black Rock Spring.

The number of canyon springs observed was very large. In the valley of Crab Creek near Krupp a spring in a small gully has been improved by digging, and by a system of piping has been made to supply excellent water to a house and barnyard. One of the most important springs in the region is that known as Skooten Spring, which is situated near the eastern end of Saddle Mountain, and supplies a small pond without outlet, and consequently strongly alkaline. There is no other surface water within some 15 miles, and therefore the horses that graze within that radius resort to this watering place in great numbers.

Professor Russell has suggested a method of increasing the flow from the springs that issue from sedimentary layers in the basalt series by driving horizontal tunnels in the water-bearing strata. No springs improved in this way were observed, although small well-like pits have been sunk in many places. It is probable that horizontal tunneling might be employed to advantage in many cases, but the springs generally seem to occur in comparatively thin layers of

scoriæ or cinders, so that the digging of a tunnel would be considerably retarded by the resistance of hard rock above and below.

There is a water prospect of peculiar history on the northeastern slope of Saddle Mountain. Tradition has it that the sounds of rushing water used to attract the attention of passers-by, and tunneling was undertaken in the hope of tapping the subterranean stream. The writer visited the abandoned and caved-in excavation, which had penetrated only the mantle of soil and basalt rubble, but could not detect the faintest whisper of the alleged underground current.

FISSURE SPRINGS.

There remain to be described two very large springs, one of which is certainly a fissure spring from a deep source, while the other is only doubtfully to be classed as a fissure spring. The first of these is Clerf Spring, in Kittitas Valley, the second is a group of springs on a terrace of the Columbia overlooking the foot of Priest Rapids.

CLERF SPRING.

The salient features of Clerf Spring have been mentioned by Mr. George Otis Smith.[a] It is situated at the side of a small canyon emptying into the east end of Kittitas Valley. The natural flow has been increased about fourfold by an excavation that affords a good exposure of the rocks from which the spring issues. Fine shales and shaly sandstones of the Ellensburg formation here rest upon the vesicular surface of a basalt flow. The water boils up from the bottom of the excavation, which has penetrated the basalt to a slight extent, and probably emerges from crevices in the rock concealed by fine débris. The water is of good quality, but noticeably warm, the temperature being 62° F. An irrigating ditch leads from the spring along the side of the canyon to the side of the main valley. The supply from this fountain, which is all utilized in the dry season, is estimated to be about 120 miner's inches.

The high temperature of the water and the mode of its emergence show that this spring is, in effect, a natural artesian well and that its water is forced up by hydrostatic pressure from a considerable depth. The facts point unmistakably to the existence in this vicinity of conditions favorable to obtaining flowing artesian water. An experiment in this direction has been made, and boring has been begun within a few rods of the spring in the hope of obtaining an additional supply of water. The well has been carried to a depth of about 40 feet in the basalt, and water has been obtained which, on a test, rose just above the surface. The drilling was done with poor machinery

[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Washington: Water-Sup. and Irr. Paper No. 55, U. S. Geol. Survey, 1901, p. 45.

and evidently by an inexperienced driller. The progress in the solid basalt is said to have generally been less than a foot a day, or about one-sixth of the rate attained by experienced drillers in the wheat country. The well was finally abandoned and has caved in about the top so as to be at present useless.

HARRISON SPRINGS.

At the southwest extremity of the arid plain that stretches south from the base of Saddle Ridge there is a strip of land about 3 miles long by one-half mile wide which is green with a luxuriant growth of swamp hay. On the border of this oasis there are clustered a group of farm buildings and corrals and a strip of old orchard, flourishing and bearing abundantly. A large force of farmers and cattle men live upon the place, which is generally known as the Harrison ranch.

Along a line in the central part of the hay meadow there are a number of small ponds bordered with tules and other aquatic plants. The ponds are very deep in proportion to their small area, and are perennially supplied from beneath with living water colder than that of the river and of good quality. The overflow originally escaped to the river from both ends of the meadow, but since the east end is now banked by a sand dune the escape is mainly to the west, where it falls over the terrace in a stream of probably several hundred miner's inches.

In its original state the area now occupied by this oasis was a marshy lake, which has only been made available for agriculture by artificial drainage. Even now the meadow land beneath the surface is saturated with water and quakes in many places beneath the foot. It is therefore unfit for growing grain or alfalfa. The present crop is chiefly of wild swamp hay, but an endeavor is being made to improve the quality of the forage by gradually supplanting it with domesticated grasses. The crop is mainly used on the ranch for the winter feeding of cattle and horses, whose summer range extends over a large part of the desert to the north. About 1,500 head of stock were wintered here in 1901–2.

The waste of the large surplus of water from these springs, in a land where water is so precious, must strike anyone as a thing to be regretted, and gives rise to the inquiry whether more of it might not be used. The hope of this does not appear to be very good. The strip of land between the meadow and the river is not in general more than 5 feet above the springs, and might, perhaps, be irrigated readily by windmills, but the soil is very gravelly and apparently infertile, so that it is doubtful whether the expense of irrigating it would be repaid. The ranch is situated on the lowest terrace above the actual flood plain of the river, and there seems to be little or no land that can profitably be irrigated from the springs by gravity alone. On the

other hand, however, it appears possible to extend the area of hay land by draining some of the broad shallow ponds at the eastern end of the meadows.

The geologic conditions which give rise to these springs can not be observed directly, for the bed rock in this vicinity is mostly concealed. A few small outcrops of basalt are seen north of the oasis, and this rock forms the bed of the river at Priest Rapids. The riverward escarpment of the terrace upon which the springs are situated

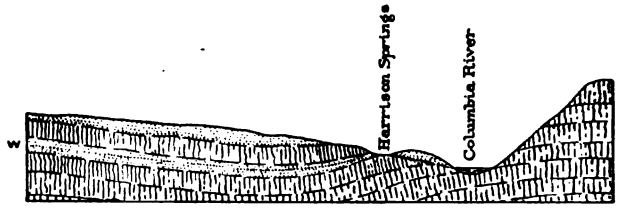

FIG. 2.—Section illustrating explanation of Harrison Springs on the hypothesis that the water-bearing stratum has been tapped by erosion.

is of gravel, without rock exposures. The rock from which the water issues is not exposed. From the rather meager observations two explanations of the phenomena observed seem possible. Under either hypothesis the water is supposed to flow from some porous reservoir stratum (possibly the white tuff bed exposed near Sentinel Bluffs) fed by rain and snow falling on Saddle Mountain.

According to the first hypothesis, illustrated in fig. 2, the water-bearing stratum has been tapped by erosion. The fact that the water issues along a comparatively short line may be explained on the sup-

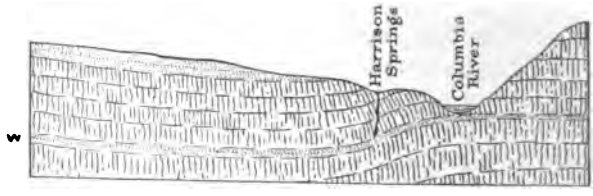

FIG. 3.—Section illustrating explanation of Harrison Springs on the hypothesis that the springs are situated along a break in the basalt.

position that the water-bearing stratum is lenticular, and that a tongue-like projection has been cut off here. The tuff bed already mentioned appears, indeed, to have a lenticular form, since it is not seen west of the river at Sentinel Bluffs nor south of it at Priest Rapids.

An alternative explanation may, however, be given for Harrison Springs. (See fig. 3.) The fact that the springs are in a straight line parallel to the structural ridge across the river strongly suggests that they may be situated along a break in the basalt formed by the

earth forces that produced the ridge. This hypothesis is, perhaps, on the whole, somewhat more probable than the one already given. The coolness of the water, however, shows that it does not come from a great depth. The fracture, if it exists, may therefore be a minor one in the basalt above the water-bearing stratum, produced by the rather sharp bending of the basalt and not extending indefinitely downward like a true fault fissure.

SURFACE WELLS.

The numerous farm wells in Kittitas Valley belong mainly to the surface type and are sunk in valley alluvium. There are some, however, which penetrate Ellensburg sandstones for short distances and probably derive their supply from distant sources, thus being classifiable genetically with the deep wells. Their discussion, therefore, will be deferred to a later section.

The surface wells proper of the valley perhaps require no description. The few wells very near Columbia River, and the more numerous ones in Crab Creek bottom, which derive their supply from the underflow of the neighboring streams, may also be passed with brief mention.

The great majority of the shallow wells in the Columbia Plains are sunk to depths varying from 13 to 75 feet in the alluvial deposits that floor the dry coulees and their tributary gulches. The suggestion advanced in the discussion of springs, that the water on reaching bed rock has been concentrated in the old subsurface channels according to natural laws of drainage, is equally applicable in the case of these wells, for the nature of springs and of surface wells is, in fact, essentially the same, save that in the former the configuration of the ground is such that the water-saturated bed emerges on the surface.

A notable well of this class supplies the small village of Ephrata. Just west of the town a canyon opens out upon the gravelly plain. There is a small surface flow in the lower part of the canyon, which vanishes in the broad delta-like alluvial fan below its mouth, where a shallow well taps the sunken stream, and a windmill pumps it into a tank, from which it is distributed through a system of pipes. There are several other wells in the neighborhood of the town, generally from 50 to 75 feet deep, and gathering their supply from gravel that was probably laid down by the Columbia in Glacial time.

Of more especial interest are the fairly numerous wells on the plateau west of Coulee City. These have all been dug by hand, for the most part in the sand, clay, and gravel brought down by the ancient glaciers from the north. Two such wells are situated in sec. 14, R. 25, T. 27 E., one of which penetrates 42 feet of gravel, clay, and sand and 18 feet of basalt, while the other attains a depth of 65 feet without reaching basalt.

The quantity and stability of the supply from surface wells vary widely in different cases. The wells last mentioned appear to meet all demands except when the wind for the windmills fails for a considerable time. The wells in the coulees often give an abundant supply; one in Lind Coulee, notably, met the domestic needs at one time of a score of families. On the other hand, some surface wells often fail to meet the demands made upon them in the dry season, and it may be said in general that the chances of obtaining a generous and reliable supply of water are smaller in surface wells than in deep borings in the basalt.

DEEP WELLS.

INTRODUCTORY STATEMENT.

Historically the deep well represents the latest development in the methods of obtaining water on the Columbia Plains. When the fertility of the plateau lands was recognized their settlement became inevitable, but the question of water supply was at first a serious one. The waste of time and labor involved in hauling from the widely scattered springs, often necessitating the pulling of a heavy tank over miles of deeply rutted and hilly road, led the wheat growers to seek a method by which a sufficient supply of water could be obtained at any desired point, even upon the summits of the plateau. The deep drilled wells solve the problem successfully, and they are being put down by all who are able to meet the expense, which is often considerable.

The charges for well drilling in the southern part of the wheat lands are as follows: In soil, gravel, etc., above basalt, 50 cents a foot; in rock (which is generally in great part massive basalt, though other varieties after the first basalt is struck are not differentiated), $2.25 per foot for the first 300 feet and 50 cents per foot additional for each 100 feet below that depth. Water for the engine, coal, and board for the outfit are furnished by the owner of the ranch.

In the vicinity of Ritzville the terms are slightly higher; for the first 300 feet the charge is there $2.50, and 50 cents higher for each additional 50 feet. On these terms, however, the driller furnishes coal, the cost of which is estimated at about 25 cents for each foot drilled in basalt. In all cases water is guaranteed, and the risk of losing tools (which generally also necessitates abandoning the hole) is borne by the driller. The average cost of a well at these rates is probably not far from $800, though it reaches a maximum of over $2,000.

The rates charged for drilling appear fairly reasonable considering the cost of machinery, the risk of loss, and the degree of skill required. The hardness of the rocks is such as to call for very careful tempering of the drills and skill and patience in manipulation.

There seems to be a strong personal factor in the success of drilling operations, many drillers having records unmarred by loss of tools or failure to obtain water, while the work of others seems frequently to end in disaster.

In Kittitas Valley deep wells have never attained importance as a source of water supply. This fact is due to the more favored condition of the valley. In the lower portion shallow hand-dug wells have been found adequate to supply the wants of the house and barnyard. The much larger demands of irrigation have been supplied more or less satisfactorily with water from the Yakima and its tributaries. Thus, although it has long been recognized by intelligent observers that the basin-like structure of the valley is favorable to artesian water, the demand for an artesian supply has not been strong enough to give rise to energetic prospecting. The two borings that have been made were unsuccessful and have thus tended to destroy the hope of obtaining flowing wells in the valley, but, as will be shown later, these experiments were so inefficiently carried out as to have little evidential value.

The purpose of the following discussion is primarily economic, and it will attain its object if it helps the reader to decide to what extent he can profitably invest in deep borings. It is the scientific questions involved in this problem that the writer proposes to treat here. It will be shown, for one thing, to what depths, approximately, it is necessary to go in a given part of the district for a sufficient supply. But a question which is perhaps more important, and whose solution requires scientific investigation of a special kind, is whether artesian water exists in the region. The fact that no flowing wells exist at present is not conclusive evidence for a negative answer to this question, since the all-important rules for the proper casing of wells have been generally ignored. Furthermore, an endeavor will be made to show that underground pressure, even though insufficient to raise water to the surface, may often advantageously be utilized by proper casing.

Since this paper is intended chiefly for the benefit of nonscientific readers, it will be necessary, in order to make the discussion of artesian problems clear, to insert at this point a statement of the principles upon which artesian flow depends, and to show how those principles should be applied in prospecting for artesian waters and in constructing artesian wells.

GENERAL THEORY OF ARTESIAN WATER.

The conditions that usually determine the flow of an artesian well may be illustrated as follows: Suppose two water-tight basins of similar form are so fastened together as to lie one within the other, with a small water-filled space between. Let the upper basin be per-

forated, and let the perforation be tightly fitted with a tube. According to a simple and familiar law, the water will rise in this tube to the height at which it stands in the space between the basins, and if the mouth of the tube be lower than the rim of the lower vessel and the latter be kept full by some external supply a constant stream will issue from the pipe. Such an arrangement as is here described would be a working model of an artesian basin. The construction of our model might be slightly modified, however, without essentially changing the principles involved. For the basin-shaped space we may substitute one between two superposed troughs or between two inclined boards, provided that the space is closed except along its upper edge. In either case a flow would be obtained from any aperture below the lowest point of the rim of the reservoir space. The essential principle illustrated in this simple manner is expressed by the familiar saying that "water seeks its own level."

In natural artesian districts, however, the conditions do not have the ideal simplicity of our primitive model. A number of additional factors come into play, materially complicating the problem. We

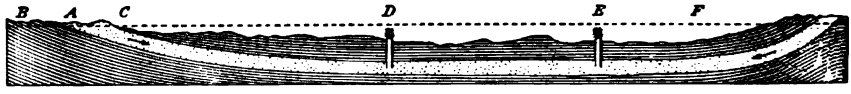

FIG. 4.—Ideal section illustrating the requisite conditions for artesian wells. (After Chamberlin.)

have now to show to what extent natural conditions are represented by our model, and in what respects the difference of actual from ideal conditions leads to modification of the simple rules of artesian flow.

Suppose a basin-like valley, underlain by a stratified series of rocks that have a basin structure, so that the form of the layers corresponds in a general way to that of the surface of the ground. Suppose that in this stratified series there lies a bed of porous material, such as a coarse, open sandstone, capable of absorbing and storing a large quantity of water, and that this porous bed is overlain and underlain by some material, such as compact clay shale, which is practically water-tight. If the upturned edges of the sandstone stratum are exposed along the slopes of the hills surrounding the valley, they will absorb a portion of the rain falling upon the hills, and, in some cases, of streams flowing over the outcrop. The porous bed will become saturated with water and constitute a great underground reservoir, from which an artesian flow may be obtained by sinking a well at some point lower than the exposed area where the bed absorbs its supply. (See figs. 4, 5, 6.)

While the conditions in the basin valley are similar to those of the simple model in the most essential respects, there are two noteworthy particulars in which the natural and the ideal conditions differ.

In our working model we have for a reservoir an open space, and the basins that form its walls are water-tight. In nature the reservoir is generally constituted by an aggregation of minute but connected pores between the grains or fragments that constitute the water-bearing bed, and the confining strata are never absolutely impervious. Both these modifications of ideal conditions have an important influence upon the flow of artesian streams.

First, the water flowing to a well through the small interstitial spaces encounters a notable amount of frictional resistance, which has the effect of retarding the flow. In order to counterbalance the consequent loss of artesian pressure and obtain a generous flow the well must be situated at a point considerably lower than the area of absorption and the depression must be increased in proportion to the distance from the source of supply.

Second, leakage through the confining strata, by diminishing artesian pressure, acts in the same unfavorable way as frictional resistance, though loss from this source is not likely to be serious if the region between the area of supply and the wells is elevated.

When, therefore, we inquire as to whether the stratigraphic conditions in a given region are favorable to the hope of obtaining artesian water we must not look for absolute impermeability in the strata confining the water beds. It is necessary only that the resistance which the water must overcome in escaping through the confining strata be large in comparison with that which it encounters in flowing through the porous stratum. In other words, the stratigraphic conditions are fulfilled when we have a relatively permeable stratum confined between strata that are relatively impermeable.

We have still to consider another difference, perhaps even more important, between theoretical and actual conditions. We have assumed up to this point the absence of any exposure of the water-bearing stratum affording opportunity for leakage lower than the mouth of the artesian wells. It is probable that this condition is

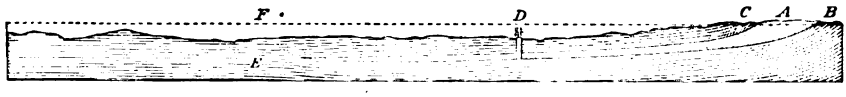

FIG. 5.—Section illustrating thinning out of a porous water-bearing bed. (After Chamberlin.)

rarely fulfilled in nature. Most valleys are drained by streams, and the gorge by which a river leaves a basin-like structural depression will cut the water-bearing stratum and expose it at a lower elevation than any point on the valley floor. An ideal artesian basin must be topographically an undrained basin, and that is an exceptional topographic form. It is probable that in the great majority of artesian districts the water-bearing stratum is cut at points lower than any of the wells.

The effect of such leakage upon the behavior of artesian water must therefore be inquired into and the reason shown why it does not destroy underground pressure in the imperfect reservoirs. It is a more or less familiar truth that moving underground water follows the path of least resistance. More definitely and specifically, we may say that the water at any given point in an artesian basin will tend to escape to the surface by the route on which it will have to do the least work in overcoming resistance. The resistances to be overcome are friction and gravitation. It is readily conceivable that in the area near a well the water can more easily overcome the gravitative resistance and rise to the surface as an artesian flow than the great frictional resistance it would encounter in passing to a distant low outcrop, even though aided by gravity.

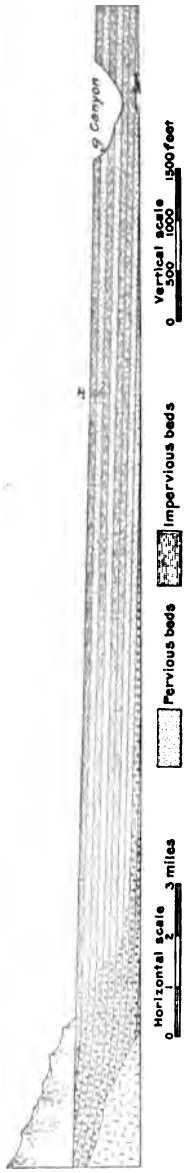

FIG. 6.—Section of an artesian slope. (After Russell.)

An illustration of the principle here involved may be cited which is familiar to the experience of everyone. In a city house furnished with a system of water pipes, the turning on of faucets in the lower stories will not generally stop the flow from the faucets on the floors above, though it may materially diminish its force and volume.

The considerations set forth in the later paragraphs have been recognized by others,[a] and Professor Russell, from whose paper[b] the accompanying figure (fig. 6) has been taken, has proposed for the form of reservoir in question the term "artesian slope." It seems to the present writer, however, that it has not been sufficiently recognized that leakage in natural reservoirs is almost universal. When a district is examined with reference to artesian conditions, hope of obtaining artesian flows should not be abandoned on finding that the water-bearing strata were exposed at low levels, but an attempt should rather be made to estimate the degree to which the existing natural leakage will injure the artesian reservoir. It will be interesting to discuss briefly the data upon which such estimates may be based.

It is obvious, in the first place, that the danger from leakage is great in proportion as low outcrops are extensive. In the case of a basin valley, for example, it is desirable that the

[a] Chamberlin, T. C. Requisite and qualifying conditions of artesian wells: Fifth Ann. Rept U. S. Geol. Survey, 1884, p. 142, fig. 17.

[b] Bull. U. S. Geol. Survey No. 199, 1902, p. 157.

gorge through which the river emerges be narrow in proportion to the size of the expanded part of the valley. Another fact, perhaps less evident, is that it is disadvantageous for the river to have cut down deeply below the general level of the valley floor. In such a case the water-bearing stratum may be very extensively exposed, and the artesian basin indeed be divided into two scoop-shaped segments with the water bed exposed along the entire edge of each. By a similar course of reasoning it may be perceived that in a given artesian district porous beds lying low down in the series will in general be less extensively exposed along the rivers than higher beds (see fig. 14, p. 65).

The effect of leakage is dependent, in the second place, on the proximity of the low-level outcrops to the place where the well is to be sunk. In the close vicinity of such outcrops the route of escape by the natural exposure of the porous stratum may offer less resistance than must be overcome in rising through the wells. At points more remote from the region of leakage, on the other hand, the loss of pressure will be much less serious, and at great distances it may become negligible. In a long synclinal valley, underlain by a water-bearing stratum having the form of a trough with open ends, the chances of obtaining an artesian flow in the central portions of the depression would generally be excellent, and loss of pressure by leakage need be apprehended only near the ends of the trough. In the case of an inclined stratum exposed along the greater portion of its lower edges the danger from leakage would probably reach a maximum. The diminution of pressure from leakage would be greatest near the low outcrops; but, on the other hand, those situated farther away would generally be at a disadvantage from being on higher ground, and the most favorable location for wells would be in an intermediate zone where conditions were somewhat balanced.

From the foregoing discussion it should be evident that the prospector for artesian water may, according to his judgment and experience, make a more or less approximate estimate of the effect of natural leakage. Each case must of course be considered for itself, yet certain rough generalizations can be made. In the central portion of a basin valley, from which a river flows by a narrow gorge and does not deeply trench the valley floor, or in the middle of a synclinal trough of great length, the loss of pressure by leakage is not likely to diminish the pressure in a fatal degree. On the other hand, a well sunk to an inclined stratum extensively exposed at a low level will generally not succeed unless the stratum is of very great extent and other conditions are favorable. The effect of leakage is, however, at best a somewhat indefinite factor in the artesian problem.

The discussion to this point has related to the structural, stratigraphic, and topographic conditions influencing artesian flows, or, in other words, to the nature of the reservoir. Of no less importance is the supply which fills this reservoir and supplies the loss from wells and springs. In order that a well shall continue to flow, the water level in the artesian reservoir must be kept higher than the mouth of the well. This supply, as has been briefly noted, is chiefly from rain falling upon the high exposures of the porous stratum and immediately absorbed. It may, however, be augmented by a considerable amount not falling directly upon the area of absorption, but flowing over it for short distances in temporary rills, and by leakage from streams that flow across the outcrop of the porous stratum. A case illustrating leakage from a stream is cited by Mr. George Otis Smith in his description of the Moxee-Atanum basin.[a] In this manner areas remote from the zone of outcrop may contribute to the artesian reservoir.

The amount of water supplied to an artesian basin depends on the area of the zone of absorption and on the amount of precipitation along that zone. The zone of absorption is necessarily higher than the flowing wells and consequently lies usually in a region of greater rainfall. Its area, however, is generally small in proportion to that of the whole artesian basin, and the amount of water that can be drawn from the underground reservoir, far from being unlimited, is very definitely determined by the average precipitation on a comparatively small area. If the amount drawn off by wells and springs exceeds the amount annually furnished by rain and snow, a diminution of artesian pressure must result. Many wells that gave a powerful stream at the beginning have ceased to flow when borings have multiplied in their vicinity. This danger of wasting the artesian supply has been recognized by the legislature of the State of Washington,[b] which has framed a wise law compelling owners to cap their wells during the rainy season (from October 1 to April 1) and to use only such amounts during that period as are necessary for domestic purposes and stock.

We may now recapitulate the necessary conditions of artesian flow, as follows:

(1) A porous stratum capable of absorbing large quantities of water and allowing it free passage.

(2) Relatively impermeable strata above and below, capable of confining most of the water under pressure.

(3) An exposure of the edge of the porous stratum where it may absorb water falling upon it, and, to some extent, that of rills and streams flowing across it.

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[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Wash.: Water-Sup. and Irr Paper No. 55, U. S. Geol. Survey, 1901, p. 56.

[b] Stat. Washington, chap. 121 (H. B. No. 203).

(4) An inclination or folding of the water-bearing stratum and a corresponding slope of the surface of the ground, so that the proposed wells may be located below the zone of supply.

(5) Absence of low-level outcrops sufficiently extensive and sufficiently near the proposed wells to cause great loss of pressure by leakage.

(6) A sufficient supply of rain water to maintain the artesian head.

DATA CONCERNING DEEP WATERS.

ARTESIAN DIVISIONS OF THE REGION.

We may now proceed to discuss, in the light of the general principles just laid down, the artesian problems for the region here considered. In this discussion we must use the facts already set forth concerning the natural conditions of the region and, further, the well records that give direct evidence regarding the occurrence and behavior of underground waters.

The facts can not be discussed for the region as a whole, since conditions vary considerably in different portions. A division can be made, however, into districts in each of which the natural conditions are fairly uniform. Those in which deep wells already exist are designated (1) the Connell-Ritzville district, (2) the Hartline district, (3) the Quincy district, and (4) the Kittitas Valley district. In the desert area traversed by Saddle Ridge there are no deep wells, but the natural conditions will be discussed separately for the portions of the desert south of and north of that prominent structural feature.

STRATIGRAPHIC CONDITIONS IN COLUMBIA PLAINS.

The stratigraphic conditions are so uniform throughout the Columbia Plains that it will be profitable to consider these conditions from the artesian standpoint before proceeding to discuss the special features obtaining in each of the districts just blocked out, all of which lie within the Columbia Plains except the Kittitas Valley, where the stratigraphy is somewhat different and must be discussed separately.

In that portion of the Columbia Plains considered in this report the Ellensburg beds are so distributed as to afford little ground for the hope that an artesian supply can be obtained from them. The obstacles to such a hope are the facts that the high outcrops receive but a very small supply of atmospheric water, and that the beds are too extensively dissected by the canyons and coulees.

If artesian water is to be obtained in this portion of the plains it must be from the basalt series or from beds of sandstone intercalated with the basalt. In discussing the artesian problem for this area, therefore, it is important to consider whether the manner in which the basalt series is built up is favorable to the storage of deep water and its conservation under pressure. The required condition, it

will be remembered, is that strata capable of containing much water and of allowing it to pass with comparative freedom shall alternate with strata that are comparatively impervious.

The lithologic character of the basalt, including its texture and the structural features of the massive flows and pyroclastic beds, and the character and extent of the materials other than basalt intercalated with the upper layers of the series, have been described in a previous section. The facts pertinent to the present purpose may be recapitulated briefly as follows: The lava series is built up mainly of a great number of massive flows with rough vesicular surfaces. The massive lava is universally cut up by joints developed in the process of cooling into columns, plates, and irregular blocks. Intercalated with the massive flows are beds of porous tuff and breccia, which, however, occur in small volume as compared with the true lavas. A few beds of acid tuff and of sandstone are interbedded with the upper layers of the series, but are very rare in the lower portion of the section.

To the hasty observer the vesicular or "honeycombed" upper portions of the basalt flows might seem well adapted for the storage of water, but a little thought will show that such an idea is largely fallacious. The vesicles of the amygdaloids are not connected, but are inclosed chambers incapable of receiving water except by slow infiltration and quite incapable of allowing its free passage. To quote the language of Chamberlin, the porosity of a water-bearing stratum should be of an "interstitial and not a vesicular kind."

But if the vesicular portions of the flows are not available for water storage there seems reason to believe that there are spaces between the lava flows, thin and irregular but extensive, that might serve as reservoirs. The surface of a freshly cooled lava flow, though level and monotonous in its broad aspects, is rough in detail. A second flood rolling upon a surface thoroughly cooled will probably not generally completely fill the inequalities of the preexisting surface. The crust forming upon the top and front of the liquid flow, broken and rolled under by its advancing motion, will often form a rough layer that does not fit closely into the minor unevenness of the cooled lava beneath. It is believed that waterways are often constituted by the spaces thus left by the failure of a more or less viscous flow to fill completely the roughnesses of the surface upon which it was poured. Though small in the beginning, these subterranean spaces may subsequently become enlarged by the solvent action of deep waters.

The ability of the porous tuff beds and breccias to absorb and contain water is evident to anyone familiar with their character, and it is believed that they probably contain the most generous supplies of water to be found in the basalt series in the region here considered.

Some of the beds of siliceous tuff and sandstone already described

are probably well fitted for water storage, but they are apparently of only local importance. They may be found a source of water in the low-lying southwestern portion of the region, but the records of wells and observations of natural sections go to show that sandy beds are so rare in the eastern and northeastern portion as to be practically negligible.

We have next to consider whether the massive basalt is capable of confining under pressure the water stored in the porous beds.

The massive compact basalt is in itself a practically impermeable rock. The universal presence, however, of crevices, due to contraction partings, has led some observers to believe that the basalt is in general incapable of confining water under pressure. With this view the writer has been led to disagree, mainly by certain facts learned from well records.

Water in the deep wells of the plains is never found in any useful quantity in the massive basalt itself, but always in softer material between the compact layers. It is known to exist under pressure sufficient to raise it 250 feet in certain localities where there is no evidence of any strata of clay or silt which could have been efficient in preventing its escape from the pervious bed. It is concluded, therefore, that the basalt does to a notable extent have the ability to confine water under pressure. The crevices in the massive rock, especially in the case of flows where the columns are small and irregular, are believed to be not only minute but generally not continuous throughout the flow, and to allow the passage of water in but comparatively small amount. At the same time it is admitted that jointed basalt is probably less efficient material for a confining stratum than clay or fine shale.

To sum up, then, it appears that the basalt series presents an alternation of strata of differing permeability favorable to the storage of artesian water, though the stratigraphic conditions are probably not so favorable as they are in a series of open sandstones alternating with beds of fine shale or clay. The water-bearing layers in the basalt series consist of acid tuffs and sandstones, thin irregular spaces between the flows, and basaltic tuffs and breccias. The massive basalt, although universally creviced, is considered to be of low permeability in comparison with these porous layers.

CONNELL-RITZVILLE DISTRICT.

By this name we may designate that portion of the wheat lands which lies south of upper Crab Creek. This area, though very extensive, is characterized by a similarity of conditions that justifies its treatment as a unit in the discussion of deep wells.

Structure.—The structure of the basalt underlying this district is

not easily made out except through a broad study of the region, because the inclination of the lava flows, as observed in the walls of the coulees, is almost imperceptible in amount, and its direction and degree can not generally be determined except by careful instrumental observations, which the writer was not able to make. The interpretation of the structure is based largely on topographic grounds. The general surface of the land east of the Northern Pacific, lying at an elevation of nearly 2,000 feet above sea level, probably coincides nearly with the original surface of the basalt, or is below that surface, which may have been largely reduced by erosion. The desert area to the west and southwest, lying at a considerably lower level, is underlain in part by Ellensburg beds, which cover the basalt to a depth of several hundred feet. The surface of the basalt is, therefore, farther below the surface of the ground in this region than in the more elevated lands to the northeast. It may therefore be inferred that the basalt underlying the Connell-Ritzville district has in general a very gentle inclination to the southwest.

Topography.—The upper portion of the basalt series in this district is trenched by a large number of coulees, having a maximum depth below the surface of about 400 feet, though when the thickness of the gravel deposits in their bottoms is considered it appears that the trenches in the bed rock have depths as great as 600 feet. The average depth of the coulees is greatest in the southwestern portion of the district, which is nearest the master streams of the Columbia Plains, the Snake and the Columbia. Far to the west the basalt is deeply cut into by Columbia River, which exposes strata many hundred feet below the top of the series.

The general intrenchment in the wheat lands has an important relation to the deep wells. It is evident that any porous strata existing in the basalt series at horizons above the general level of the neighboring canyon bottoms would be extensively exposed to leakage along the canyon walls, and that while it might at some localities carry considerable water, it could not be expected to contain it under artesian pressure.

Supply.—The writer is unable to present any information based on detailed observation in regard to a region of supply for the deep-lying porous strata under the eastern wheat lands. Study of maps and level lines shows that along the eastern boundary of Washington and in northern Idaho there is an elevated region which receives a more abundant rainfall than the district considered. Part of this region was seen by the writer in traveling by rail between Ritzville and Spokane. It is a surface of erosion with many inequalities that would probably increase its efficiency as a gathering ground. Some of the lower beds in the basalt series may be exposed there, and may

absorb a portion of the rainfall. A supply may also be furnished from the edge of the basalt formation at the base of the mountains in Idaho, though that region is so far distant that it seems doubtful whether it may be assumed that any porous beds extend continuously thence to the Ritzville region.

Well records.—The reader may gather from the facts above stated that the natural conditions, considered apart from experimental evidence, in the Connell-Ritzville district do not seem greatly to encourage the hope of obtaining artesian water. There are several factors of uncertainty in the theoretical problem, however, that make it desirable to scrutinize all the evidence obtainable from wells that have already been sunk. The appended list gives the data collected by the writer in regard to these. The list does not include by any means all the wells in the district, but it is believed that the expenditure of time necessary to make an exhaustive list would not have been justified, and that the data obtained will serve the main purposes of the examination.

A few words applying to all the data for the Columbia Plains may also be prefaced in regard to the fullness and reliability of the well records obtained. Owing to the fact that the rock penetrated is mostly basalt, not intercalated with any considerable amounts of tuffs, sandstones, or shales, it has not become customary to keep any regular records of the material through which the drill passes. There has been simply a differentiation between "rock" and "dirt," for the purpose of reckoning charges. Any more detailed information that has been gathered, therefore, has been supplied from the memory of drillers or of others interested in the wells. In regard to depth, the figures have in some cases been taken from written records, but in others from the memory of owners and drillers. It is believed, however, since most of the wells are of comparatively recent construction, that the figures given are substantially accurate.

Partial list of wells in Connell-Ritzville district, Washington.

Owner.	Location.	Depth.	Depth to surface of water.	Depth of soil, etc.	Remarks.
1. Northern Pacific R. R.	Eltopia	151	115	.....	
2. Do	Lake	354	284	.....	
3. J. W. Gover	Sec. 24, T. 13, R. 30	311	297	.....	
4. Jas. Elgin	Sec. 33, T. 13, R. 32	323	283	[a] 84	Water at 310 feet.
5. Brayden Bros	Sec. 32, T. 13, R. 32	674	629	14	
6. M. C. Moore	Sec. 21, T. 13, R. 32	78	.....	.....	Supply not abundant.

[a] 80 dirt; 4 gravel.

Partial list of wells in Connell-Ritzville district, Washington—Continued.

Owner.	Location.	Depth.	Depth to surface of water.	Depth of soil, etc.	Remarks.
7. H. C. Baker	Sec. 29, T. 13, R. 33	575	551	23	
8. Northern Pacific R. R.	Connell	228	.....	[a] 6 [b] 180	
9. H. W. Brummond	Sec. 8, T. 14, R. 32	410	395	42	
10. Eugene Adams	Sec. 6, T. 14, R. 32	510	.....	.....	
11. Wm. Mittelstadt	Sec. 35, T. 15. R. 31	318	293	30	
12. Wm. Dickinson	Sec. 25, T. 15, R. 31	360	330	75	
13. Wm. Brown	Sec. 13, T. 15, R. 31	425	325	50	
14. Town	Hatton	300	7	37	Water rises.
15. Andrew Newland	Sec. 35, T. 16, R. 31	430	380	50	
16. Cunningham	Sec. 10, T. 16, R. 32	255	150	.....	In bottom of coulee.
17. C. S. Hedrick	Sec. 34, T. 16, R. 32	300	250	40	
18. Merrill	Below Lind	.....	320	.....	
19. McMannaman and Van Marten	East of Lind	130	100	.....	
20. Northern Pacific R. R.	Lind	225	32	25	Water rose to top of basalt.
21. Town	do	286	30	10	
22. Adam Buehler	Sec. 15, T. 18, R. 33	363	328	14	
23. Louis Pflugard	Sec. 14, T. 18, R. 33	318	298	35	
24. Fred Scheel	Sec. 8, T. 18, R. 36	297	172	25	
25. Chas. Lakes	Sec. 32, T. 19, R. 33	300	250	40	
26.	Sec. 30, T. 19, R. 33	110	20	20	In coulee.
27. Dan Scott	Sec. 35, T. 19, R. 34	358	258	50	
28. Henry Myers	Sec. 32, T. 19, R. 34	350	250	70	
29. A. Johanson	Sec. 32, T. 19, R. 34	250	235	70	
30. City of Ritzville	Sec 23, T. 19, R. 35	360	200	50	Elevation, 1890.
31. J. W. Johnson	Ritzville	180	.....	46	
32. Scott	6 miles west of Ritzville.	358	270	.....	
33. Odessa Mill	Sec. 5, T. 21, R. 33	137	40	23	
34.	Sec. 26, T. 21, R. 30	211	206	31	Water in red "honeycomb rock;" lateral flow washed away drillings.

[a] Soil. [b] Gravel.

A few general statements may be deduced from the list concerning these wells.

In comparing depths, allowance must be made for the fact that some wells are sunk from the high plateau surface of the wheat lands, while others are situated in the coulees, from 50 to 400 feet below the general upland levels. Comparing the average depths of wells in the uplands, we obtain the following results: For the thirteenth and fourteenth rows of townships, 406 feet; for the fifteenth and sixteenth, 367 feet; for the eighteenth and nineteenth, 327 feet. There is thus, in general, a slight increase in average depth from north to south. The explanation of this fact is probably to be found in the greater depth of the coulees in the southern portion of the district, which is near the master stream of the region, where the ancient streams were most deeply intrenched.

The figures in regard to depth of soil have interest, though without direct bearing on water-supply problems. The soil is seen to be in general very deep, apparently attaining its greatest depth on the brows of slopes, where the conditions are most favorable for wind accumulation. Some indication of the amount of hardpan was gathered from descriptions of wells. This material seems to be thickest in the neighborhood of Ritzville. The depth of gravel in certain of the coulee bottoms is also given by the well records.

In regard to the character of the rock in which water is found, the information is, of course, not very definite, since it is based upon the relative ease with which the material is penetrated by the drill and by the appearance of small fragments brought up by the sand pump. No case is recorded, however, where the water-bearing stratum is sandstone, a material that could hardly fail to be recognized. The water-bearing material is always softer than the massive rock, and is usually described as "honeycomb," less seldom as "brown gravel," or "bowlder formation," etc., but no true waterworn gravels were seen in any of the natural exposures of the basaltic series. The testimony all seems to indicate that the deep water is generally found in porous or fragmental basalt.

The third column, headed "depth to water surface," contains data that are of the highest interest, because they give the most positive evidence obtainable in regard to artesian conditions. Drilling is usually stopped almost immediately upon obtaining a good supply of water, and any considerable difference between the corresponding figures in the third and fourth columns usually indicates that the water has risen from the water-bearing stratum. Such a rise indicates that the underground water is under pressure and, therefore, in the general sense of the word, artesian.

This artesian rise of water varies in different portions of the region. To the south it attains 70 feet in the railroad well at Lake. But

nowhere in the southern portion of the district is the rise considerable enough to give much hope of obtaining artesian flows.

The most encouraging information was obtained in the vicinity of Lind, where the town well has water standing within 30 feet of the surface, having risen some 250 feet by artesian pressure. Another well was recently bored there for the Northern Pacific Railway Company to a depth of 225 feet. The water was in a porous rock which extended from within 60 feet of the surface to the bottom, where the principal flow was obtained. The water rose 200 feet, to the top of bed rock. Another well in Lind Coulee, a short distance below the town, tapped water which quickly rose to within 3 feet of the surface, but sank afterwards some 20 feet. The latter fact is accounted for on the supposition that the loose surface material was packed and rendered partly impervious by the friction of the drill rope, but became porous again after the water had washed the fine material from the sides of the bore. A consideration of this case should enforce the important lesson that the failure of the water to reach the surface may often be due, not to lack of sufficient pressure, but to leakage through porous material forming the sides of the upper portion of the well. There seems to be very good reason for the hope that artesian water, at least in small quantity, might be obtained at Lind by properly casing the wells.

Northward, in the neighborhood of Ritzville, a rise generally occurs. The water seems to lie at an average depth of about 300 feet below the upland surface, from which depth it is forced up by artesian pressure from 50 to 100 feet, resting from 250 to 200 feet below the general plateau level. In the town well at Ritzville the water surface lies less than 100 feet below the nearest point in the coulee bottom. In the mill well at Odessa the water has risen within 40 feet of the surface, or within 17 feet of the top of the basalt. In a well 110 feet deep in sec. 30, T. 19, R. 33, the water comes within 20 feet of the mouth, and probably escapes by leakage. Attention is called to the importance of the fact that a rise of water in the wells is very general throughout the region. This matter will receive further discussion in the sequel.

Another phenomenon indicating the distant source of the water is a lateral flow noted in one or two cases and shown by the washing away of the drillings.

In regard to the quality and quantity of the water a few general statements may be made. Nearly all of the deep wells, so far as known, yield a supply sufficient to meet all demands for present uses, and one that remains constant throughout the year. The largest supply known to have been furnished was given by the Ritzville city well, which was guaranteed by the contractors to furnish 5,000

gallons an hour and which has, in fact, furnished a stream of that volume for twenty-four hours without perceptible lowering. The quality of the deep waters is generally excellent and far superior to that of surface wells or springs, the underground water being soft and of good flavor. Regarding temperature, the data gathered were too meager to form the basis of discussion, but there is as usual a general increase of temperature with depth.

HARTLINE DISTRICT.

The Hartline district is defined as comprising the western part of the valley traversed by the branch line to Coulee City, in which lie the villages of Parnell, Wilbur, and Hartline.

Structure.—The layers of basalt beneath Hartline Valley have been gently flexed into a synclinal or trough-like form, limited on the south by a low, gently arching swell and on the north by a plateau. The western end of the valley meets the Grand Coulee almost at its own level and is faced by the moderate slope up which the road to the plateau beyond is laid. This slope is in a measure conformable with the structure of the basalt underlying it, the layers of basalt being turned up in such a way as to close up the western end of the syncline. The eastern end of the Hartline trough was not visited, but observations from a moving train give reason to believe that its bottom rises in that direction and that the syncline dies out upon the high plateau land. The Hartline district therefore seems to lie in a spoon-like structural depression, a fact which in itself favors the hope of obtaining artesian water.

Topography.—The greatest imperfection in the Hartline basin is its deep dissection by the Grand Coulee. The northern portion of the coulee lies nearly 400 feet, and the southern portion below the old cataract nearly 800 feet, lower than the floor of the valley at Hartline. The close proximity of a chasm so deep must have a very considerable effect in reducing pressure in the basin by affording opportunities for leakage from the water-bearing strata.

Supply.—In regard to the source of the underground water of the district, the remarks on that matter in the description of the southern wheat lands apply equally in this place. The principal area of absorption probably lies on the high land to the east, but the writer can supply no data based on actual observation.

Well records.—Theoretical consideration of the conditions in Hartline Valley do not, on the whole, indicate very decisively the existence of a true artesian basin, and the evidence of the wells, as in the case of the southern wheat lands, will be useful in aiding a judgment on the possibility of obtaining surface flows. Most of the data exhibited in the following table have been supplied by Mr. J. A. Wilburn, of Hartline, one of the principal drillers of the district.

Partial list of wells in the Hartline district, Washington.

Owner.	Locality.	Depth.	Depth to water surface.	Thickness of soil.	Remarks.
		Feet.	*Feet.*	*Feet.*	
33. Wasapa	Sec. 14, T. 24, R. 29	400	.....	.....	No water.
34. H. Childs	Sec. 19, T. 24, R. 30	203	173	16	
35. Tom Elder	Sec. 18, T. 24, R. 30	147	115	28	
36. Do	Sec. 12, T. 24, R. 30	168	.....	.....	
37. Rodgers	Sec. 7, T. 24, R. 30	168	138	22	Water in a crevice.
38. J. Harris	Sec. 4, T. 24, R. 30	210	196	22	
39. Sinclair Bros	Sec. 29, T. 25. R. 30	137	83	20	
40. Do	Sec. 33, T. 25, R. 30	293	193	13	
41. Jim Hill	Sec. 6, T. 25, R. 30	242	42	32	
42. A. J. Burke	Sec. 25, T. 25, R. 29	116	65	45	
43. John McDonald	Sec. 24, T. 25, R. 29	184	40	28	Do.
44 Buckhannon	Sec. 11, T. 25, R. 29	173	40	16	

The water is said by Mr. Wilburn to occur generally in "brown gravel," though it is more probable that the material thus designated is fragmental or scoriaceous basalt rather than true alluvial gravel. In two cases, however, the water was found in a crevice, which may have been either a joint opening or a space between two flows, formed in the manner described on page 68.

The figures in the third column are of especial interest. In the last 4 wells of the list the water has risen to within short distances of the surface, varying from 40 to 65 feet. In the Hill well it is within 10 feet of the top of the basalt. In the other wells on higher ground the water has generally risen, but the pressure has not been sufficient to lift the water as near the top as in the other cases. The general rise of water indicates considerable underground pressure, and gives reason to hope that artesian flows might be obtained from the lower wells if they were properly cased.

QUINCY DISTRICT.

This district comprises the northwest quarter of what has been termed the desert, upon the northern border of which lies the small hamlet of Quincy, where 4 drilled wells have been sunk.

Structure.—Quincy lies in a structural depression, though the fact is not evident at once, since the basin is a broad one and has been greatly marred by erosion. Just north of the village a structural slope rises to the ridge overlooking Willow Springs, and 18 miles to the south a low arch forms the opposite side of the east-west trough.

Far to the east the basalt rises to the wheat-lands plateau, and to the west the lava flows are turned up, forming the long gentle slope of Table Mountain.

Topography.—If, however, only the upper portion of the basalt series is considered, it appears that the Quincy basin is merely a trough, open at both ends. The Grand Coulee and its southern continuation have cut down at least 150 feet, and the Columbia 800 feet, below the top of the basalt series. The proximity of the river gorge is, of course, disadvantageous.

Supply.—Only a small amount of water can be supplied to the upper strata of the basalt series from the ridges north and south of the Quincy basin, on which the rainfall is extremely light. There may be a slight contribution from middle Crab Creek, though there is no positive evidence of the fact. The deeper-lying porous beds may draw a supply from the far-distant elevated land east of the Ritzville region, but it is doubtful whether there are any such beds continuous for so great distances.

Well records.—On the whole, the uncertainty of supply, combined with the deep dissection of the basin, discourages the hope of obtaining surface flows, at least any of moderate depth, in the Quincy district. The well records, of which a list follows, confirm these inferences:

List of wells in the Quincy district, Washington.

Owner.	Location.	Total depth.	Depth to water.	Depth of soil, etc.
		Feet.	*Feet.*	*Feet.*
	Sec. 12, T. 20, R. 24	194	190	40
	Do	194	190	40
	Do	260	190	40
Marble	Sec. 6, T. 20, R. 24	330	190	22

The water is found in soft material that seems to be basaltic tuff. Two soft layers were penetrated in the Marble well and one in the wells in the town itself.

AREAS WITHOUT DEEP WELLS.

Desert near lower Crab Creek.—In the region between Saddle Mountain and the next ridge north the conditions are very similar to those that obtain in the Quincy district. Between these two anticlinal ridges is a synclinal trough, rising in a general way toward the wheat lands at the east and closed at the west by the structural slope of Table Mountain.

Topographically this area is generally lower than the Quincy district. It is bordered on the west by Columbia Canyon, which here is not very deep, and is trenched by Crab Creek coulee in its central and southern portions.

The conditions of supply for this desert section seem to be unfavorable, for it is bordered on all sides by arid country. A large portion of the front of Saddle Mountain is a cliff, along which no water could be furnished to the porous beds underlying the region north of it.

The conclusion reached by consideration of natural conditions and by comparison with other districts is that, while water could probably be obtained from deep wells sunk down as far as the level of Crab Creek, there would be no reasonable hope of obtaining artesian flows in this portion of the desert.

Bench south of Saddle Mountain.—This broad unwatered area is underlain by Ellensburg beds, which in turn lie upon basalt, with interbedded acidic tuff and sandstone. The base of the Ellensburg and portions of the upper layers in the basalt series are exposed along the slope of Saddle Mountain and far to the east. The district is on the marginal portion of a great structural basin, in which lie Pasco and the Rattlesnake Desert.

The strata underlying the broad expanse of this bench are so extensively dissected by the Columbia that there seems nothing to warrant expectation of their containing water under sufficient pressure to rise to the surface. There is little doubt, however, that water could be obtained in this district from wells of moderate depth. The abundant flow of cool water from Harrison Springs appears to indicate the presence of a saturated bed at no very great distance below the surface, but the water in this layer, finding such free outlet at the springs, can not be under sufficient pressure to raise it very far above their level.

The terrace land near the head of White Bluffs and across the Columbia is lower, and therefore more favorably situated. It has not been sufficiently examined by the writer, however, to entitle him to a very definite opinion in regard to the prospects of artesian water. The arid character of the surrounding country and its dissection by Columbia, Yakima, and Snake rivers are unfavorable features.

Two experimental borings have been made in this region. One is at Pasco, where a well has been sunk and cased to a depth of about 400 feet in sandstone without obtaining a flow. The second is on the right bank of the Columbia, below Craig's ranch, where a boring 400 feet deep has been made without any successful result. This hole had been abandoned at last accounts, owing to the loss of the drilling tools. Neither of the borings described reached basalt, and neither

seems to furnish conclusive evidence that artesian water could not be obtained in the low arid region south of the area examined in this reconnaissance.

KITTITAS VALLEY.

Stratigraphy.—Sections of the Ellensburg beds, wherever studied, have shown an alternation of layers varying in coarseness, which is favorable to the conservation of artesian water under pressure. In the White Bluff section such alternation has been noted. In Kittitas Valley the Ellensburg beds exposed in numerous sections are found to consist of gravels, sandstones, and fine silty stuff in frequent alternation. The lowermost part of the section, according to Mr. George Otis Smith, contains a large proportion of gravel, and is therefore especially adapted to store a large quantity of water, which would be confined between the basalt below and the silty materials above. The basal portion of the Ellensburg in Kittitas Valley therefore seems well fitted by its lithologic character to serve as an artesian reservoir.

The Ellensburg beds underlie the floor of Kittitas Valley to a depth of several hundred feet, possibly a thousand feet or more. In the Moxee basin artesian water is found, at depths generally ranging between 600 and 1,000 feet, near the base of the Ellensburg formation. It is probable that if artesian water is to be found in Kittitas Valley it will probably be in the same stratigraphic position and at about the same depths.

Structure.—The structure of Kittitas Valley may best be comprehended by reference to the map and structure sections. It will be seen that the dips on all sides of the valley converge toward its center, and that the basin structure is complete though not simple. The form of the basin may be roughly reproduced by taking a sheet of paper and pinching up a wrinkle in one end, when a scoop that will hold water will be formed. The wrinkle is represented by the anticlinal ridge between Clerf Springs and the main southeastern continuation of Kittitas Valley, known as the "Badger Pocket."

Topography.—The structural conditions here seem to fulfill the artesian requirements almost ideally. The cross section of the valley shown in Pl. II might well serve as a diagram of a typical basin. Like nearly all structural basins, however, its rim is cut by a stream which exposes the edges of the water-bearing series from top to bottom, and we have to consider to what extent the pressure is thus diminished by leakage. General considerations already stated in the theoretical discussion of artesian conditions lead to the belief that the exposures in the narrow canyons by which the river enters and leaves the broad valley are not extensive enough to cause great loss of pres-

sure. Another consideration urged by Mr. Smith [a] may also be noted here.

The Moxee artesian basin is cut by Yakima River in exactly the same manner as the Kittitas basin. Mr. Smith considers that leakage at the low outcrops in the Yakima gap has been to a large extent prevented by the action of mountain-making pressure, which has produced intense folding along the southern side of the Atanum-Moxee valley, and has incidentally compacted and indurated the beds of sandstones. Mr. Smith cites evidence of similar intense dynamic action at the head of Yakima Canyon, and suggests that leakage at this point may be largely prevented in the manner indicated. While the present writer is hardly inclined to concede to this agency the degree of efficiency that Mr. Smith ascribes to it, he believes that it may, by increasing the resistance to leakage, help to maintain pressure in the water-bearing strata.

Supply.—The supply of water for the reservoir strata in this case must be imbibed along the outcrop of the base of the Ellensburg on the surrounding hills. This supply will not consist solely, however, of rain water falling on the slopes and immediately absorbed, but may be largely augmented by leakage from the bottoms of streams that flow across the upturned edges of the sandstones.

Probably the greater portion of the water that finds its way into the Ellensburg sandstones of this valley comes from the slopes of Table Mountain to the north and northeast. The outcrop along this slope is probably washed by more rain than falls in other portions of the valley, and is crossed by a great number of streams which can hardly fail to make some contribution to the underground supply. On the whole a large amount of water must enter the Ellensburg sandstones along its very extensive high outcrops, and should be sufficient to supply many flowing wells.

Well records.—As may be gathered from the preceding paragraphs, the conditions of structure, stratigraphy, topography, and supply all seem to favor the hope of obtaining artesian water in this valley. But to many practical persons it may seem that the conclusions arrived at by theoretical deduction are less valid than evidence derived by actual experiment. Some attempts have been made to obtain artesian water in this district, without any positive success. It will be well to review the results of well digging in the Ellensburg sandstones, and to try to judge the value of the evidence derived in this manner.

Information was obtained from Mr. Joseph Preece of several hand-dug and drilled wells in the southeastern part of the valley. They penetrate the Ellensburg sandstones to slight depths only, and prob-

[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Wash.: Water-Sup. and Irr. Paper No. 55, U. S. Geol. Survey, 1901, p. 41.

ably do not approach the base of the series by hundreds of feet. On the Stoney ranch, 6 miles southeast of the Preece ranch, there is a well 150 feet deep in which the water rose 25 feet after the water-bearing layer was first struck.

In an old well 45 feet deep on the Preece ranch, dug by the owner, the water rapidly rose 10 feet from the bottom, though the sides had remained perfectly dry until the water-bearing stratum was struck. The water was soft, noticeably warm, and maintained a constant temperature throughout the year, so that it would "steam" in the cold air of winter. The warmth of the water at so moderate a depth indicates its derivation from a distant source, and its sudden rise from the water-bearing layer shows it to be under pressure. In short, the water is artesian in the broad sense of the word. No attempt was made to case the wells or to determine by a test how far the water would rise in an open tube connected with the porous stratum if it were prevented from escaping except by way of the tube.

The Sanders well, north of Ellensburg, which is the only deep boring ever sunk in Kittitas Valley, is said to have reached basalt after passing through 700 feet of sandstone and clay. The tools were lost at that depth and the well was abandoned with the water standing 40 feet below the surface. The negative result of this experimental boring has been pretty generally accepted as demonstrating the futility of any further attempts to obtain artesian water in Kittitas Valley.[a]

Before we accept this discouraging view, however, we should ascertain whether the record is trustworthy and whether the well was properly cased. On neither point has the writer been able to obtain satisfactory information. There is reason to believe, however, that the driller was both inexperienced and incompetent, and altogether unfit to be intrusted with the important task of boring an experimental well. The evidence afforded by the Sanders well, therefore, should by no means be accepted as conclusive.

But we are not without positive evidence in a strong degree contradictory to that just considered in the phenomena at the Clerf Spring. Clerf Spring is, in effect, a natural flowing artesian well. A well was bored near the spring in 1900 in the hope of augmenting the supply obtained from the spring, with the result that water was obtained at a depth of 40 feet below the surface of the basalt, which rose to the surface in an open pipe. The drilling at this point was made with poor machinery and by an incompetent driller. The hole has been abandoned and allowed to cave in about the top, though it is probable

[a] Russell, I. C., Geological reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893, p. 69.

that a more generous supply could be obtained by going deeper. The well as it stands gives no new evidence, however, beyond that afforded by the spring, which demonstrates the existence beneath this locality of underground water under pressure sufficient to force it up to a level considerably higher than that of the floor of the valley.

After a consideration from a theoretical standpoint of the natural conditions obtaining in the district and an examination of the evidence afforded by existing wells, the writer is confident that artesian flows would be obtained at most points in the valley floor lying below the level of Clerf Spring by properly constructed wells reaching to the base of the Ellensburg series. Anyone intending to prospect for an artesian supply should, however, intrust the task of boring to a driller of known skill, experience, and integrity.

If the possibility of tapping an artesian reservoir be admitted, however, it still remains open to question whether the expense of deep borings would be justified, in view of the prospective construction of high ditches from the upper Yakima River. When the proposed ditches shall have been built they may efficiently supply all the area above and beyond the present irrigation ditches that could be benefited by an artesian supply. It may, however, be considered desirable to have a town water supply from a deep source free from the danger of polution, which is never entirely absent from surface streams.

SUGGESTIONS IN REGARD TO DEEP WELLS.

A few suggestions may appropriately be given here to guide drillers and others interested in deep wells, and especially to direct intelligent prospecting for artesian water.

TESTING ARTESIAN PRESSURE.

It is remarkable, in view of the encouraging indications of underground pressure afforded by certain wells in the vicinity of Hartline and of Lind, that no tests whatever have been made in the wheat lands to determine definitely whether artesian flows might be obtained from properly cased wells. A few such tests, intelligently made, might show, at no great expense, the existence of an important natural resource in the region. The development of flowing artesian water would not only benefit the landowners, but the drillers as well, for it would enhance the demand of their services. It would therefore be to the interest of drillers to provide themselves with the simple apparatus necessary and to test the underground pressure wherever there appears reasonable hope of obtaining a surface flow.

A general description of the kinds of apparatus used and of the methods and principles involved in such tests is given in the following extract from Chamberlin's admirable essay on artesian wells:[a]

Control of flow.—It is clear, upon consideration, that perfect control may be obtained by putting down a tube to the densest portion of the upper confining bed, if, by some device, the space surrounding it may be closed up so that no water can rise outside of the tube. Formerly this was done by a very simple and ingenious device known as the seed bag (fig. 7). A long, stout leather bag is made in the form of a cylinder, open at both ends, and just the size of the well bore. This is slipped on the lower end of the pipe, and the bottom of the bag securely fastened about the tube by wrapping with marline. A thimble just above the tie will aid in preventing slipping. It is then filled with dried flaxseed, and the upper end likewise closed around the tube. When thus adjusted it is lowered into the well to the point determined upon and supported there until the seeds swell by absorbing water. This enlarges the bag so as to fit the bore tightly and shut off all water from rising outside the pipe, and so all is compelled to ascend through the tube to the surface, or at least as high as the pressure is competent to force it.

FIG. 7.—Seed bag. *a*, Delivery tube, leading to the surface of the well, and terminating below the seed bag; *c*, a leather bag filled with dry flaxseed; *b*, marline wrappings to secure the end of the seed bag. (After Chamberlin.)

A better and more convenient, but more expensive, packing takes advantage of the expansion of rubber disks when pressed together, instead of the swelling of flaxseed. A series of thick, washer-like rings of rubber are fitted about a section of pipe, so adjusted between iron disks that, after being put down, they can be screwed together and so caused to expand laterally and completely fill the bore.

The construction of the parts and their adjustment are sufficiently indicated in the accompanying figures, which illustrate one of the forms in use.

In a form employed in the oil regions the expansion of the rubber disks, or of a single cylindrical one, is accomplished by pressing a conical hollow wedge between the pipe and the rings, thus forcing them out against the walls of the well.

In this case the packing is supported by a perforated tube—an "anchor"—reaching to the bottom of the well. As the packing in artesian wells is often located near the top, the necessity for support from below excludes this form in most cases.

Detection of flow.—It has been remarked above that the water may rise from the bottom to some higher portion of the well and there find escape by passing off laterally through the upper strata. In the absence of control the water does not always rise and overflow. It is a matter of some practical moment, therefore, to know when a stream is struck which may yield a flow at the surface when put under proper control. (1) Such a stream usually discovers itself by a rise of water in the well, but this is not always the case. (2) Some

[a] Chamberlain, T. C., Requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 131–172.

influence on the action of the drill is liable to be felt, which may arouse suspicion. (3) In any instance of a strong flow the drillings are apt to be carried away, so that when the sand pump fails to bring these up, or brings only coarser material, there is good reason to believe that a stream has been struck, and the proper tests should be made. In enterprises that do not require a voluminous flow, tests should usually be made when such indications appear.

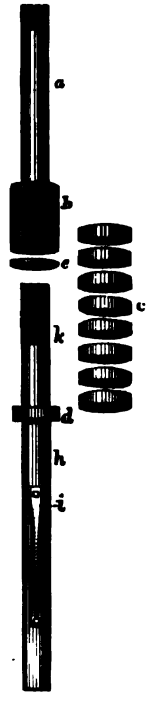

FIG. 8.—Rubber packing, shown apart. *a*, Section of delivery tube, extending to the surface; *b*, a large thimble into which *k* screws; *e*, an iron washer; *c*, a set of rubber disks fitting on *k*, between *b* and *d*: *k*, a section of pipe on which is turned a long screw fitting in the thimble *b*; *d*, a disk forming the head of the screw *k*; *h*, a section of pipe extending about 2 feet below the packing; *i*, a spring to press against the walls and hold the pipe *h* while the section *a* and thimble *b* are screwed upon *k*. (After Chamberlin.)

FIG. 9.—Rubber packing, shown screwed together as it is in the well. (After Chamberlin.)

It is ordinarily desirable to test the capacity of any stratum which gives any of these or other indications, before sinking to a lower one. It is advisable to make provision in the contract for such tests, since it is not always to the interest of the driller, once his machinery is set up and well at work, to stop at the more limited depth. The capabilities of the flow may be tested by the use of a tube and seed bag, or by rubber packing, as explained above.

Negative and false tests.—It is possible, in perfect honesty, to make both a negative and a false test. Suppose the two porous beds, *A* and *B* (fig. 10), separated by an impervious layer, are traversed and the testing of the first has been neglected, either because it failed to give encouraging indications or for other reasons. It is now desired to test these. Suppose the seed bag or rubber packing be placed above the upper one. Now, if both bear a water

level equally high, the test will be fairly made and the result will indicate their combined capacity, or if both heads are at least as high as the surface at the well the test may be accepted. But suppose that the bed *A* has been cut into by erosion, or been reached by crevices, or is otherwise defective, while the other, *B*, remains intact and bears an elevated fountain head. Under these conditions the water may flow from *B* through the bore into *A* and escape laterally through it, as illustrated in the figure. Now, in this case the result may be either simply negative or positively false and misleading. If the lateral leakage through the stratum *A* effectually disposed of the flow from *B* and there was no leakage in the upper portion of the well, the water in the test tube would stand during the test at essentially the same height as before, and the result would be negative, merely failing to indicate a possibility that really existed. If, on the other hand, there was lateral leakage through the upper strata as well as through *A*, neither alone being quite competent to dispose of the flow from *B*, then the introduction of the test pipe would cut off the upper leakage, leaving the bed *A* unable to dispose of the entire flow. In this case there would be a rise of water in the tube, and possibly a flow. The mischievousness of a test of this sort lies in the fact that it appears to be a true test, while in reality it is false and misleading. The true test in this case can only be made by placing the packing between the porous beds *A* and *B*.

FIG. 10.—Section of well illustrating a negative test.

FIG. 11.—Section of well illustrating a partial and misleading test.

2. Take another instance where two porous beds, as *A* and *B* (fig. 11), have been traversed. Let the packing be placed between these. Then (1), if *A* equals *B* in productive capacity, water will stand at the same height within and without the test pipe if there is no leakage in the upper beds. (2) If the failure to flow was due to such leakage, then a flow will result from *B*, but the additional flow which might be secured from *A* is lost (see figure). (3) If *A* has a greater head than *B*, and if there is no loss above, the water in the test pipe will actually be lower than that outside, as illustrated in fig. 12. This may be said to be an inverted test, and is less misleading than the false and negative tests, since it plainly indicates an error of manipulation. I have known of such a case of reduced head as the result of an attempted test. (4) If, however, there is in this case considerable lateral waste in the upper strata, the valuable flow from *A* will be lost, just as before the test was made, while *B* may give a rise in the tube, or even a flow, which would foster the impression that a fair test had been made, while in reality the greater flow has been lost. (5) If *A* gives a feebler flow than *B*, but has an equal head, the test will fail of being completely satisfactory only in excluding the feebler flow from *A*. (6) If, however, *A* has a lower head and is a possible means of escape

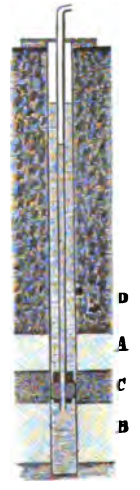

FIG. 12.—Section of well illustrating inverted test.

for the flowage from *B*, then the packing has been placed at the right point and the test gives the best results.

3. In still another case let *A* and *B* represent porous beds (fig. 13), the lower of which is so conditioned as to drain the upper one by virtue of a lower outcrop in the manner previously explained and illustrated. (1) If the drainage loss below is not complete, and if the packing is placed above *A*, as shown in fig. 13, *I*, the result will be negative if there is no leakage in the upper strata. (2) Should there be considerable loss there it will be cut off by the tube and packing, and some rise in the tube will be the result in most cases. In either instance the result is misleading, particularly in the last, because the small rise of the water is apt to allay any suspicion as to the effectiveness of the test. The real fact, however, remains that the flow from the productive stratum is mainly lost below. (3) Suppose that the packing is located between *A* and *B*, as in fig. 13, *II*, it will then shut off the flow from *A*, while that in B, because of a lower outlet, will fail to flow. Now, if there is opportunity for lateral leakage in the upper strata the water from *A* will rise in the well outside of the test pipe and pass off into these open upper beds. (4) But if no such opportunity is afforded it may rise to the surface and overflow outside of the test pipe, while the water within the test pipe will probably be found to be lower than before the test was made.

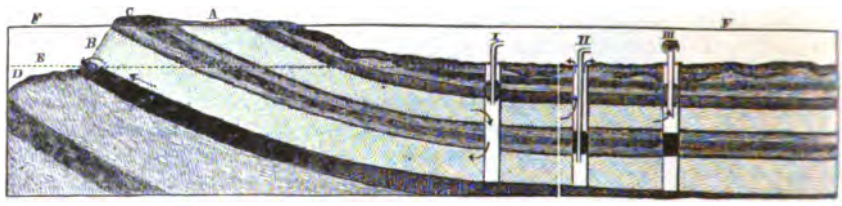

FIG. 13.—Section of strata and three wells, showing one correct and two erroneous tests.

The proper method of testing wells known or suspected to present these conditions is to sink a simple bag of seed or other obstruction to a point in the impervious stratum between *A* and *B*, which, when it tightens in its place, will shut off the flow below. Then a tube with packing sunk to a point above *A* will effectually cut off all leakage in the upper strata and the full capacity of the water bed *A* will be tested.

These examples, while not exhaustive of possible cases, illustrate the nature of defective tests and the deceptive conclusions liable to be drawn from them. The remedy is manifest. Test each water-bearing stratum as it is encountered, or else vary the final tests so as effectually to exclude all liabilities to error.

Some comment may be made on the special application of these directions in this region. In Kittitas Valley the strata encountered in the downward progress of the drill outcrop along the neighboring hill slopes at successively higher elevations, so that there does not seem to be much danger of leakage from a water-bearing stratum to the one beneath, and a plug inserted just above the highest strong flow should be sufficient. In the wheat lands, where conditions are less thoroughly understood, more care should be taken to make the tests exhaustive.

It has been noted that in wells sunk from the plateau levels of the wheat lands water is generally found at about the same depth as in the bottoms of the neighboring coulees. An artesian flow could

hardly be expected at a less depth, for the extensively dissected upper strata would be too leaky to hold water under pressure. Wells on high ground, therefore, should be sunk lower than the bottom of any neighboring coulee and the test plug inserted below all porous layers that are exposed in the coulee walls. In wells sunk in canyon bottoms it would perhaps answer in most cases to insert the plug in the first layer of compact basalt below the loose and porous surface material.

By way of summarizing this brief consideration of artesian tests it is desired to state emphatically the following important points:

(1) The fact that the water does not overflow from an uncased well does not prove that an artesian flow might not be developed under proper conditions.

(2) A well in which water rises appreciably is worthy of being exhaustively tested, unless the nonexistence of artesian conditions in its neighborhood has been proved, and the tests should be carried out with an understanding of the principles that govern artesian flow.

(3) It is unnecessarily wasteful to case a well before it has been tested. The preliminary tests may be made with inexpensive apparatus, thus saving the heavy expense of casing until it is known to be justifiable.

DEPTH OF EXPERIMENTAL BORINGS.

It is a question of some moment to what depth it is proper to carry experimental borings. An idea is widely prevalent that the chances of obtaining artesian water increase with the depth of the well, and even that artesian water may be obtained at any place if the well goes deep enough. This notion has a certain basis in the fact that deeper strata are less liable to be tapped by erosion than higher ones. Under certain conditions, however, which are illustrated in fig. 14, the deeper strata may be less likely to yield a flow than those above.

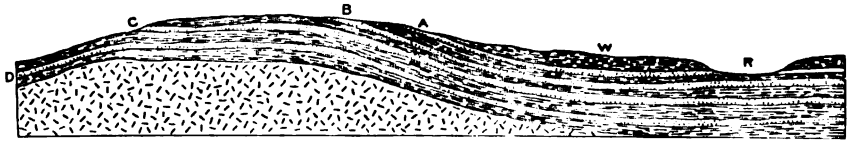

FIG. 14.—Ideal section showing relative probability of obtaining artesian flow at various depths. The stratum A is tapped by the river at R, while C and D are unfavorably situated for receiving a supply. B is capable of imbibing a good supply along its upper edge, and is not cut by the river, so that it is likely to yield a flow from a well sunk at W.

Many drillers in the wheat lands have thought that it would be worth while to sink wells to a depth of from 1,000 to 1,500 feet, in order to reach below the strata that are extensively exposed in the river canyons. Such a belief should not be adopted hastily. These deep strata would probably be less exposed to leakage, although the

writer is not sufficiently acquainted with the region to the east to speak positively, but it is doubtful whether they are favorably exposed to take in a supply available in the wheat lands. The doubt existing on this point in the present state of our knowledge should be frankly faced by anyone who contemplates putting down a very deep well. Before any such costly experiments are made some of the more favorably situated wells of the present moderate depths should be thoroughly tested. In wells to be sunk in the future each water-bearing layer should be tested as soon as reached, and if a satisfactory flow is developed at any point the owner should rest satisfied and not tempt fortune by continuing to greater depths.

CASING NONFLOWING WELLS.

If upon test a flow be developed, the well should be cased down to the point at which it is found that the packing is most advantageously located. But it does not seem wise or economical to confine casing to those wells that develop a surface flow. Suppose a well in which the underground pressure is sufficient to force the water in an open tube, inserted with a tight joint above the porous water-bearing layer, to within 50 feet of the surface, but that in its rise through the uncased well it meets a leaky, porous bed through which it escapes at 100 feet from the surface. In such a case as this the windmill or other pumping engine must raise the water 100 feet, when, if the underground pressure were fully conserved, the water need be lifted only half that distance. There is a clear waste of 50 per cent of the power, for, as is evident to all who are acquainted with the elementary principles of mechanics, a pump capable of lifting 1,000 gallons per hour through a vertical distance of 100 feet could lift 2,000 gallons per hour through half that height. The comparatively slight expense of packing the lower end of the pipe might in many cases be repaid time and time again by the saving in power where power is a source of considerable expenditure, or by the increased yield of water where all the water developed can be used to advantage.

Two qualifying phrases in the last sentence require some further explanation. In the vast majority of the deep wells now existing the pumping engines are windmills, and the cost of power is confined to the small annual expenditure for repairs, oil, etc., plus the ordinary wear and tear on the machine. Moreover, the amount of water furnished by a single mill is usually sufficient for all farm uses. Under such circumstances as these, where the running expenses are almost nothing and the supply meets all demands, there seems to be little inducement to make even a small outlay for packing the well pipe.

Where, however, a large and constant supply, such as is required to furnish a town water system, is demanded, a gasoline or steam pump is generally used. The necessary fuel is then a constant

source of expense, and, consequently, a possible saving of power, such as may be accomplished by packing, is worthy of careful consideration.

In the second place, if the rancher were able to use economically a large quantity of water it would be desirable for him to draw from his well the greatest amount that his windmill could supply under the most favorable conditions. It seems to the writer that such a use for the surplus above what is needed for ordinary farm uses is to be found in the irrigation of fruits and vegetables. While in the region east of the Columbia the conditions are such that horticulture will probably never become a leading industry, it seems certain that vegetables, small fruits, and certain orchard fruits might be produced in greater quantity and of much better quality than they are at present if the fullest use were made of the possibilities of irrigation from wells. If such a use were found for all the water available, the desirability of packing in all cases where the water level in the well could thereby be materially heightened is evident.

Efficient and systematic irrigation of gardens from deep wells would involve the construction of reservoirs, either wooden tanks or excavations lined with masonry or sod. The methods of irrigation can not, however, be dealt with in this paper. Those interested in the subject will do well to refer to Mr. Newell's recent work on irrigation,[a] where all the branches of that important art are treated fully.

CONCLUSION.

This report may be closed appropriately with a brief recapitulation of the more important points developed in the preceding pages on the deep wells of east-central Washington.

In the wheat lands the records of numerous wells demonstrate that abundant water of good quality can be obtained from porous layers in the basalt series at depths varying from 40 to 670 feet. In general, the average depth at which a good supply is reached increases gradually toward the south.

The water generally rises in these wells to a greater or less extent, which proves that the deep waters beneath the wheat lands are under pressure, and that they are, therefore, in the broad sense of the term, artesian. Despite these encouraging manifestations, however, no instance is known in which an attempt has been made to measure the effective head of the artesian streams, nor has any well in the region been cased to prevent leakage through porous beds above the confining stratum of compact basalt. There is good reason to believe that

[a] Newell, F. H., Irrigation in the United States, New York, 1902.

there are wells in the wheat lands in which the water fails to reach the top solely on account of leakage through loose surface material.

It is strongly urged, therefore, that the more favorably situated wells be tested thoroughly in order that definite information may be obtained regarding artesian pressures. Directions for making such tests have been given in the appropriate place. All wells which then prove capable of giving a surface flow should be efficiently cased.

It is thought advisable not only to case any wells that will give a surface flow, but to pack the bottom of the pipe in many other wells in which the water surface could, by that means, be raised materially. Such a procedure would be economical where, on the one hand, a gasoline or steam pumping engine is used and the running expenses for fuel, etc., are considerable; or where, on the other hand, a windmill is used and the running expenses are insignificant but it is desired to augment the supply by this means if use can be found for all the water that can be obtained. It is suggested that irrigation of gardens and orchards from deep wells would afford a profitable means of utilizing most of the water that can be developed in excess of the requirements of stock and the household.

There seems to be a fairly good chance of obtaining artesian fountains in the vicinity of Lind and of Parnell and in the coulees west of the Lind-Ritzville district, but the artesian pressures are probably insufficient to raise water to the general plateau levels of the wheat lands.

In the arid range land just east of the Columbia water could be found at comparatively moderate depths, but conditions do not favor the hope of obtaining artesian flows. A number of stock wells could probably be sunk in this region to advantage, and if located at points far from any of the natural drinking places might render available some areas now largely neglected by the stock because of their distance from water. The excessively grazed stretches near the streams and springs might then have an opportunity to recuperate if the number of animals on the range could be kept within a reasonable limit. The ruin of this range seems imminent, however, unless those who have grazing interests there adopt a conservative policy. The wastefulness and shortsightedness of overstocking has too often been demonstrated by experience and only realized when the evil was past remedy.

That there would be better chances of obtaining artesian flows on the Columbia Plains by very deep borings than from some of the moderately deep wells now existing is doubtful. Deep experimental borings in the basalt are to be regarded in the present condition of our knowledge as involving considerable financial risk. The searcher for artesian water should make careful and exhaustive tests of the upper water horizons before he sinks capital in a deep boring.

The writer believes that wells sunk in the lower portions of Kittitas Valley to the base of the Ellensburg series and properly cased would yield artesian flows. If, however, a properly conducted experiment resulted in failure to obtain a flow from the Ellensburg series, the advisability of continuing the boring into the basalt underneath would be doubtful. Granting, however, that the chances of obtaining surface flows are good, the wisdom of prospecting for artesian water in Kittitas Valley must depend upon the answer to the question whether, if an artesian supply were obtained, it could be used economically.

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